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ACMA
Lockheed-Georgia

DESIGN OPTIONS STUDY
Final Report: Volume II
Approach and Summary Results

LG80ER0007 September 1980
Final Report on Contract No. F33615-78-C-0122

LOCKHEED-GEORGIA COMPANY, Marietta, Georgia

Prepared for
UNITED STATES AIR FORCE
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Wright-Patterson AFB, Ohio 45433

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The Advanced Civil/Military Aircraft (ACMA) is envisioned as an advanced-technology cargo aircraft with the potential for fulfilling the needs of both military airlift and commercial air freight in the 1990s and beyond. The ultimate goal of the Design Options Study is the development of fundamental information regarding both the military and commercial cost and effectiveness implications of the most significant transport aircraft functional design features. This volume, the Approach and Summary Results of the Design Options
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Study Final Report, provides the background for the requirement for the ACMA; a description of the approach taken in this investigation of transport aircraft design options; a summary of the initial Qualitative Assessment used to reduce the scope of the study; and finally, a summary of the results of the detailed analyses. These results include estimates of the effects on aircraft geometry and efficiency, military effectiveness, and both civil and military costs, for incorporating in the ACMA each of the design options identified in the Qualitative Assessment.

DESIGN OPTIONS STUDY

Volume II: Approach and Summary Results

LG80ER0007

September 1980

APPROVED BY: R. H. Lange

R. H. Lange, Manager
Advanced Concepts Department

LOCKHEED-GEORGIA COMPANY

A Division of Lockheed Corporation, Marietta, Georgia

FOREWORD

The Design Options Study was performed by Lockheed-Georgia for the Air Force Aeronautical Systems Division, Deputy for Development Planning, under Contract F33615-78-C-0122. This final report for the effort is presented in four volumes:

Volume I	Executive Summary
Volume II	Approach and Summary Results
Volume III	Qualitative Assessment
Volume IV	Detailed-Analysis Supporting Appendices

A fifth volume, describing the privately-developed analytical techniques used in this study has been documented as Lockheed Engineering Report LG80ER0015. This volume, which contains Lockheed Proprietary Data, will be furnished to the Government upon written request for the limited purpose of evaluating the other four volumes.

The Air Force program manager for this effort was Dr. L. W. Noggle; Dr. W. T. Mikolowsky was the Lockheed-Georgia study manager. Lockheed-Georgia personnel who participated in the Design Options Study include:

H. J. Abbey	Configuration Development
L. A. Adkins	Avionics
H. A. Bricker	Cost Analysis
E. W. Caldwell	Configuration Development
W. A. French	Propulsion and Noise Analysis
J. C. Hedstrom	Mission Analysis
J. F. Honrath	Aerodynamics
R. C. LeCroy	Mission Analysis
E. E. McBride	Stability and Control
A. McLean	Reliability
T. H. Neighbors	Maintainability
J. M. Norman	Commercial Systems Analysis
J. R. Peele	Mission Analysis
A. P. Pennock	Noise Analysis
C. E. Phillips	Maintainability
R. L. Rodgers	Mission Analysis
R. E. Stephens	Structures and Weights
R. L. Stowell	Mission Analysis
S. G. Thompson	Cost Analysis and Configuration Development
R. M. Thornton	Mission Analysis

Program management of the Design Options Study was the responsibility of the Advanced Concepts Department (R. H. Lange, manager) of the Advanced Design Division of Lockheed-Georgia.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF FIGURES (CONT'D)

LIST OF FIGURES (CONT'D)

LIST OF FIGURES (CONT'D)

LIST OF TABLES

LIST OF TABLES (CONT'D)

GLOSSARY

AAFIF	-	Automated Air Facility Information File
A/C	-	Aircraft
ACMA	-	Advanced Civil Military Aircraft
ADS	-	Aerial Delivery System
AEEC	-	Airline Electronic Engineering Committee
AFB	-	Air Force Base
ALICE	-	Aircraft Life Cycle Cost Evaluation
ANSER	-	Analytical Services, Inc.
APOD	-	Aerial Port of Debarkation
APOE	-	Aerial Port of Embarkation
ARINC	-	Aeronautical Radio, Inc.
ATA	-	Air Transport Association
¢/ATNM	-	Cents per Available Ton-Nautical Mile
CLASS	-	Cargo/Logistics Airlift Systems Study
combi	-	Combination Cargo/Passenger Aircraft
COMPASS	-	Computerized Movement Planning and Status System
CONUS	-	Continental United States
CRAF	-	Civil Reserve Air Fleet
DADS	-	Deterministic Airlift Development Simulation
DOC	-	Direct Operating Cost
E^3	-	Energy Efficient Engine
EPA	-	Environmental Protection Agency
FAA	-	Federal Aviation Administration
FAR	-	Federal Air Regulations
GRADE	-	GRaphics for Advanced Design Engineers
GASP	-	Generalized Aircraft Sizing and Performance

GLOSSARY (Cont'd)

GSPS	-	Global Satellite Positioning System
GSE	-	Ground Support Equipment
IADS	-	Innovative Aircraft Design Study
IFF/SIF	-	Identification: Friend or Foe/Selected Identification: Friend
IFR	-	Inflight Refueling
IOC	-	Initial Operational Capability
LCC	-	Life Cycle Costs
LCG	-	Load Classification Group
LCN	-	Load Classification Number
LD	-	Lower Deck
LIN	-	Line Item Number
L/D	-	Lift-to-Drag Ratio
LRU	-	Line Replaceable Unit
MAC	-	Military Airlift Command
NATO	-	North Atlantic Treaty Organization
NSN	-	National Stock Number
OR	-	Operational Readiness
O&S	-	Operation and Support
PAX	-	Passenger
POL	-	Petroleum, Oil, and Other Lubricants
RDT&E	-	Research, Development, Test and Evaluation
ROI	-	Return on Investment
RTCA	-	Radio Technical Commission
SAE	-	Society of Automotive Engineers
SFC	-	Specific Fuel Consumption
SKE	-	Station Keeping Equipment

GLOSSARY (Cont'd)

SRC	-	Standard Requirements Code (Army)
TACAN	-	Tactical Air Navigation
TOE	-	Tables of Organization and Equipment
UE	-	Unit Equipment
ULD	-	Unit Load device
UTC	-	Unit Type Code
ZFW	-	Zero Fuel Weight

I. INTRODUCTION

The Advanced Civil/Military Aircraft (ACMA) is conceived as an advanced-technology transport aircraft with the potential for fulfilling both U.S. needs for military airlift and worldwide needs for commercial airfreight in the 1990s and beyond. This document is the final report of the ACMA Design Options Study performed by Lockheed-Georgia for the Aeronautical Systems Division, Deputy for Development Planning.

The objective of the Design Options Study has been to provide fundamental information, in both military and commercial contexts, regarding the cost and effectiveness implications of the most significant functional design features of large transport aircraft. Such information can then be used by both the Air Force and by commercial operators to specify more precisely the capabilities desired in an ACMA. In addition, this study will further illuminate the overall viability of the military/commercial commonality concept for future transport aircraft as well as identify design options that will enhance the prospects of this concept.

This introductory section provides background information pertaining to the evolution of the ACMA concept, describes the objectives and elements of the Design Options Study in greater detail, and concludes with a roadmap of this volume and a brief overview of the other volumes that comprise the final report.

BACKGROUND

Since the early 1960s, the primary objective of U.S. strategic mobility forces has been to maintain "a NATO reinforcement capability that, in conjunction with our allies, prevents the (Warsaw) PACT from attaining decisive conventional superiority for any length of time." (Ref 1) To this end, several near-term mobility enhancement alternatives are being pursued that should provide the required capability, assuming adequate warning time is available to respond to a buildup of Pact forces. If there is little or no warning before the outbreak of hostilities in Europe, a substantial shortfall in airlift reinforcement capability is anticipated. (Ref 2)

The Department of Defense Annual Reports for FY79, FY80, and FY81, also place increased emphasis on the need for sufficient mobility forces to rapidly deploy and sustain combat forces in non-NATO contingencies, primarily in the Middle East and the Persian Gulf. (Ref 3) The greatest demands on mobility forces, however, according to the FY81 Annual Report, are contingencies involving simultaneous all-out deployments to both NATO and non-NATO areas. (Ref 4)

The ACMA concept has evolved in response to these potential military requirements described above. When first espoused by the Military Airlift Command (MAC) in 1974, the ACMA, then called the C-XX, was envisioned as a commercial cargo aircraft that incorporated certain design features which would enhance its military utility. (Ref 5) The commercial aircraft, when operated as part of the Civil Reserve Air Fleet (CRAF) coupled with a relatively small number of organic ACMA, would supplement and eventually replace the existing organic airlift fleet. MAC issued a Statement of Operational Need (SON) in August 1979 suggesting a joint civil/military aircraft as the preferred solution for meeting U.S. defense needs and the needs of the commercial air cargo carriers.

The uncertainties of the future air cargo market may, however, prevent the ACMA from being developed as a commercial venture. Thus, an alternative strategy is the development of the ACMA as a military airlifter, but one that will ultimately prove to be attractive as a commercial airfreighter. Such a strategy is not unreasonable, since MAC has indicated a willingness to compromise on those design features that might degrade the commercial attractiveness of the airplane (Refs 5, 6).

In either case, the potential benefits of a common military/commercial transport are significant and include:

- o Lower average unit flyaway costs due to a larger production run.
- o Amortization of development costs over a greater number of units.
- o Greatly increased emergency airlift capability provided by commercial aircraft serving in CRAF.

- Possible cost-savings by the commercial maintenance of organic military aircraft.

These expected benefits should lead to an aircraft that is superior--in terms of cost-effectiveness and profitability, respectively--to any other cargo aircraft available to the military or to commercial operators.

A common military/commercial airlifter could evolve in several different ways. For purposes of the present study, the evolution of the ACMA is assumed to include the following aspects:

- The system development phases will closely resemble a traditional military program.
- Both military and commercial interests will be considered throughout the program. Direct participation of commercial carriers is anticipated in this regard.
- Commercial aircraft will be wholly convertible (functionally) to the organic military configuration through the use of modification kits. Such conversion would occur when the commercial aircraft are activated as part of the CRAF.

Note that these groundrules still provide substantial flexibility with respect to program funding assumptions. Indeed, a parallel effort, known as the Issues of Commonality Study, addresses some of the program funding implications of the ACMA. The Issues study, which focuses on the institutional or non-design-related issues associated with a joint civil/military aircraft program (i.e., issues that cannot be resolved by some change to the mechanical design features of the aircraft), was also performed by Lockheed-Georgia for ASD. The results of the study are summarized in Reference 7.

OBJECTIVES AND APPROACH

The Design Options Study examines the design aspects of a joint civil/military transport aircraft. The ACMA is assumed to incorporate a level of advanced technology appropriate for a system with an Initial Operational Capability (IOC) in 1995. Interestingly, the previously mentioned Issues of Commonality study suggests that, given the current Federal procurement regulations as specified by the Office of Management and Budget and supporting Department of Defense and Air Force regulations, such a system could not be operational before 1995.

The focus of this effort is on those transport aircraft design features that might tend to impede development of a system suitable for both military and commercial use. Specifically, the study identifies the design features that are likely to be most troublesome from the viewpoint of commonality. For each such feature, however, design options exist that may enhance the concept of a joint program. A key element of this work is, for selected design options, the development of detailed estimates of the cost and effectiveness implications in both military and commercial contexts. A final objective of this effort is to synthesize the results in a way that will be particularly useful to both Air Force decision makers and potential civil operators.

The Design Options Study consists of two primary tasks. The first is a qualitative assessment of all aircraft design features that are particularly important to the commonality concept. For each such design feature, design options can be identified that represent the militarily desirable capability, the commercially desirable capability, and, in some cases, a potentially acceptable compromise capability. We then qualitatively evaluate the potential of each design option in terms of its prospects for enhancing commonality and compile a prioritized list of design features and associated options for more detailed analysis.

The second task was the detailed analysis of the selected design options. Our approach entails a complete redesign of a baseline aircraft each time a selected option is incorporated into the configuration. Estimates of changes from the baseline are then generated for military cost, effectiveness, and flexibility, and for commercial economics. A careful synthesis of this information is then made to provide insight into the attractiveness of the option. When appropriate, technology requirements associated with a particular option are also identified.

VOLUME AND REPORT ROADMAPS

Sections II and III of this volume present an overview of the qualitative assessment and the detailed analysis, respectively. Detailed results are summarized in Sections IV through VII as follows:

Section	Design Features
IV	Design Payload
V	Loading/Unloading Apertures
	Planform Shape of Cargo Compartment
	Floor Height
VI	Takeoff Distance/Gear Flotation
	Noise Characteristics/Engine-Out Climb Gradient
VII	Cargo Envelope
	Passenger Provisions
	Maximum Structural Payload
	Service-Life Specification
	Pressurization

Each section describes the pertinent baseline aircraft, the configurations reflecting the various design options, and a summary of the cost and effectiveness implications of each option. Concluding observations are presented in Section VIII.

Volume III of this final report describes the qualitative assessment performed as the first task of the Design Options Study.

Supporting appendices are located in Volumes IV and V. In Volume IV, appendix A is a description of the original baseline aircraft. Appendix B describes some computerized tools used in the design process. Appendices C, D, E, and F describe in detail the aircraft configurations discussed in this volume in Sections IV, V, VI, and VII, respectively.

A fifth volume, describing details of the privately-developed analytical techniques that were used in this study has been documented as a Lockheed Engineering Report. (Ref 8) In that volume, Appendix G presents the Cost

Analyses, and Appendix H covers the Effectiveness Analyses. Appendix I describes an Airfield Flexibility Analysis and finally, Appendix J describes the process by which the civil ACMA acquires kitted components to become part of the CRAF.

II. OVERVIEW OF QUALITATIVE ASSESSMENT

A cursory examination of any list of aircraft design features that could affect the ACMA leads to the realization that it is a practical impossibility to examine every configuration that represents a plausible combination of options. Consequently, the Design Options Study is divided into two parts: (1) a qualitative assessment which identifies the most appropriate options for further analysis and establishes a logical order for the second part, which is (2) a detailed examination of point-design aircraft incorporating each of the most significant design options.

This volume of the study report presents an overview of the qualitative assessment in this section, and summary descriptions and comparisons from the quantitative analyses in subsequent sections. The qualitative assessment is reported in full detail in Volume III and detailed descriptions of the characteristics of each point design are located in Volume IV.

To provide structure to the qualitative assessment, a framework was developed to assure that adequate consideration would be given to all pertinent design features and that all significant interdependencies would be taken into account. This allows assessments of the various design features and associated options to be performed in the context of a baseline configuration.

CONTEXTUAL FRAMEWORK

The ACMA design process is represented in Figure 1, which illustrates the role played by the significant initialization parameters (i.e., the inputs to the process which determine the characteristics of the system). All of the engineering, design, and development is collapsed into the single block labeled "Synthesis and Optimization."

As illustrated in Figure 1, three types of initialization parameters, usually specified by the customer, are needed; these are the required system capabilities, assumptions regarding the environment in which the aircraft will ultimately operate (e.g., the technology level established for the time frame of interest, fuel cost, etc.), and the objective function (e.g., minimum cost,

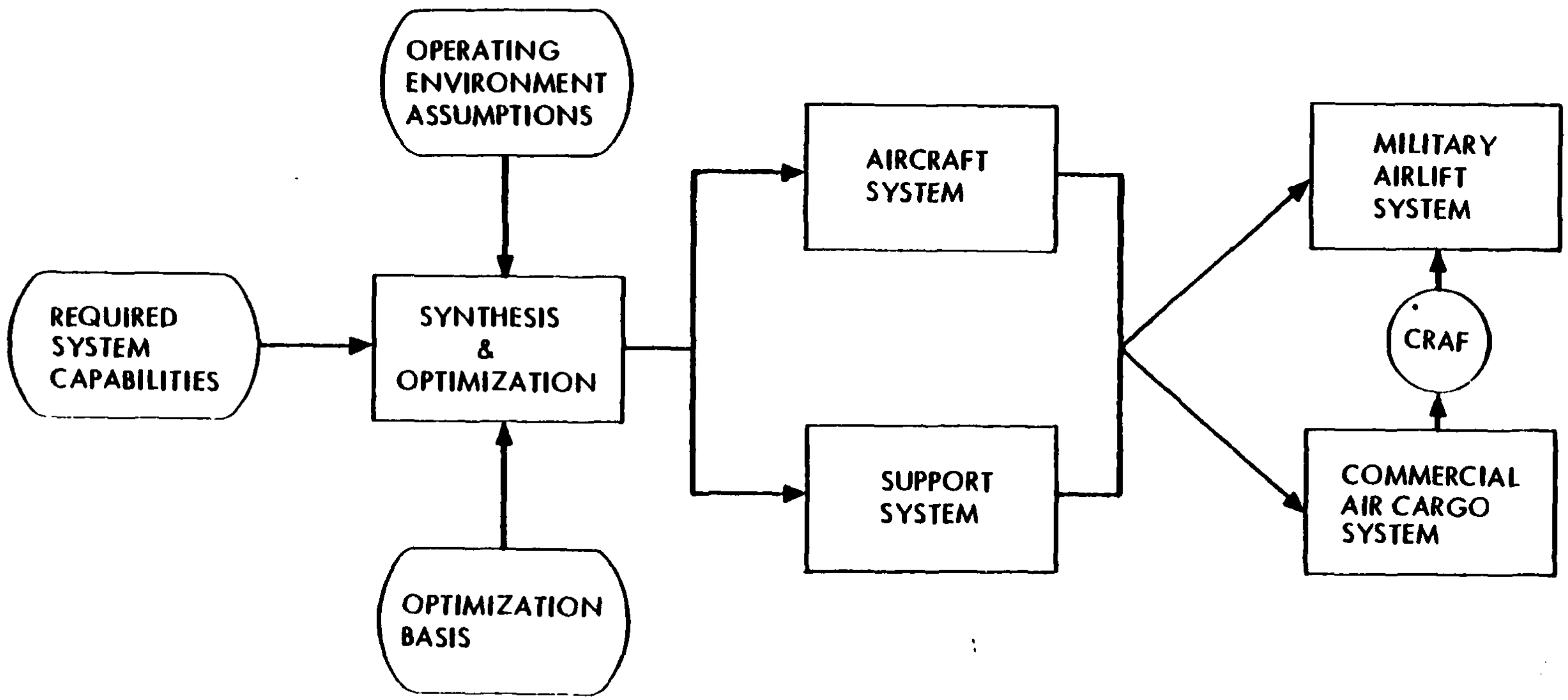


Figure 1. Overview of ACMA Design Process

minimum gross weight, etc) that forms the basis of system optimization. Given that all three types of parameters are wholly specified, the design process can, conceptually at least, generate the optimum system.

Recent studies, such as the Innovative Aircraft Design Studies (Refs 9 and 10) as well as internal Lockheed efforts, have examined in detail the implications to an ACMA of operating environment assumptions and the optimization basis. Consequently, their effect on the ACMA is reasonably well understood. The Design Options Study focuses on the remaining element--specification of required system capabilities.

To further illustrate the complexities of the process, consider that the required capabilities and optimization basis could be simply stated as the minimum life-cycle cost system for airlifting a specified mix of Army equipment from base A to base B in some fixed time period. Such a statement of the required capability would probably be only partially satisfactory, however, since the main purpose of strategic mobility forces is to provide flexibility. A system optimized under such very specific conditions could not be expected to provide much flexibility, because the airlift system design features would be established solely on the characteristics of bases A and B and the specified mix of Army equipment.

Required system capabilities are, therefore, better expressed in terms of functional capabilities. In Figure 2, the block in Figure 1 labeled "Required System Capabilities" is expanded to eight functional groupings. These are sufficient to describe the capabilities of the ACMA. Each functional grouping is broken down into applicable design features, as illustrated for the airfield compatibility functional grouping in Figure 2. Furthermore, there are usually three or more design options for each design feature, as illustrated for the takeoff distance feature. The preceding distinction between design feature and design option is used consistently throughout this work.

Table 1 list the features and options which the Air Force specified for consideration in the present study. These are included in the complete list of design features identified as having a potential impact on military/commercial

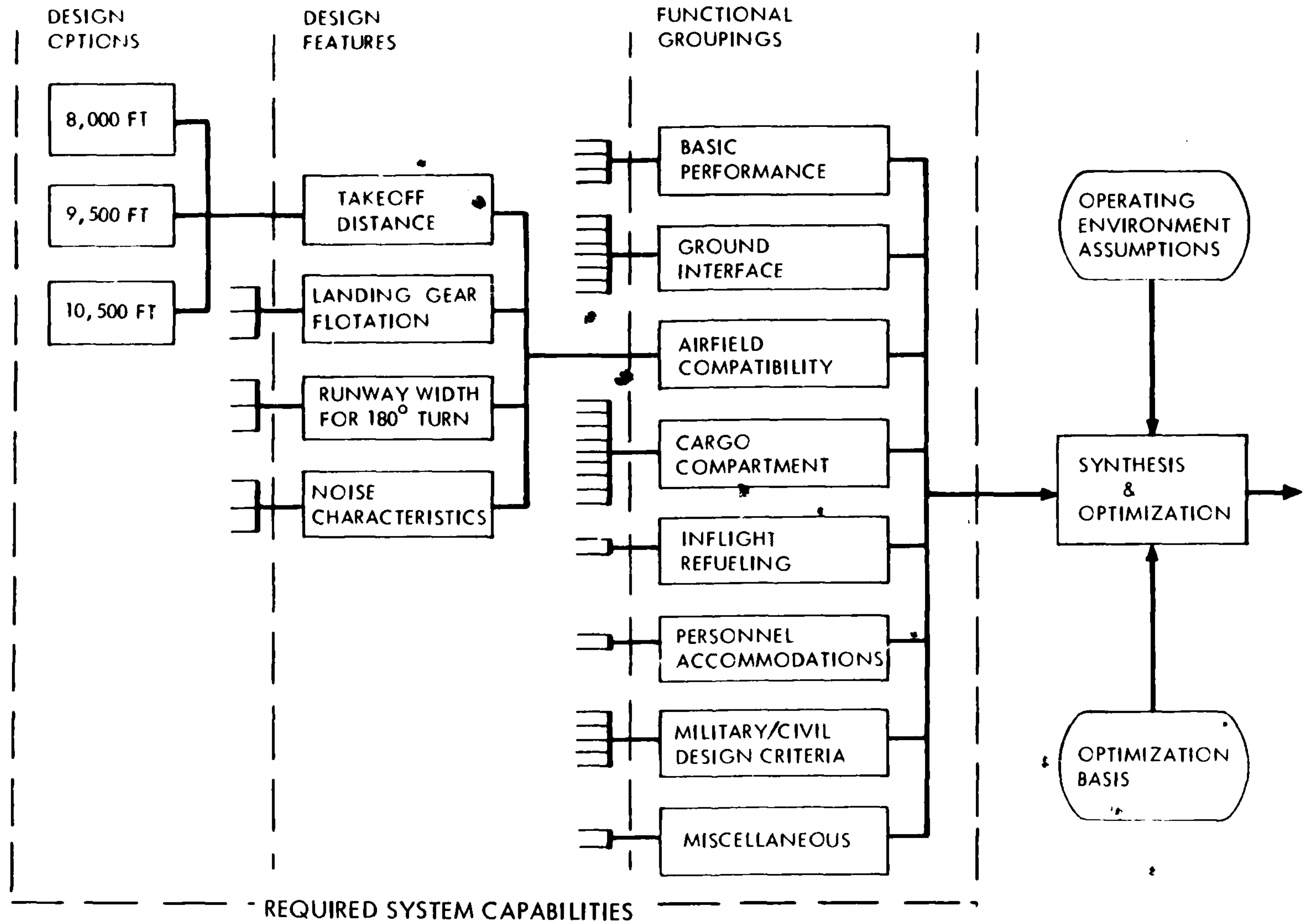


Figure 2. Specification of System Capabilities

TABLE 1
USAF-SPECIFIED ITEMS FOR CONSIDERATION

- TRUCK-BED DECK HEIGHT
- DRIVE-THRU LOADING
- REINFORCED FLOOR
- OUTSIZE / OVERSIZE CROSS-SECTION
- NAVIGATION AIDS
- 463L PALLET LOADING EQUIPMENT
- AERIAL REFUELING RECEPTACLE
- TAKEOFF DISTANCE
- ENGINE NOISE SPECIFICATION
- HIGH-FLOTATION LANDING SYSTEM
- AIRPORT COMPATIBILITY
- MAINTENANCE / SUPPORT CONCEPT
- RANGE

commonality as given in Table 2, organized into the eight functional groupings. Note that, even if only two options exist for each feature, over 100 billion different combinations are possible.

BASELINE AIRCRAFT

Building upon this framework, design options for each of the 37 relevant design features were qualitatively assessed in terms of their anticipated impact in the following areas:

- Military Considerations
  - Life Cycle Cost
  - Mission Effectiveness
  - Mission Flexibility
- Commercial Considerations
  - Direct Operating Cost
  - Indirect Operating Cost
  - Market Expansion Potential (Including return on investment)

These assessments were made in the context of the baseline aircraft depicted in Figure 3. Of greatest significance is the assumed level of technology incorporated into the baseline configuration. Given the time frame of interest for the ACMA, technology assumptions for the present effort correspond to an Initial Operational Capability (IOC) in the middle 1990s.

The most significant technology assumption for the ACMA is the use of composite resin-matrix materials, primarily graphite/epoxy, in both primary and secondary structure. The result is that composites account for 60 percent of the structural weight of the aircraft. Of course, such a level of composite utilization will require aggressive technology development to assure its availability by the 1990s.

TABLE 2
PERTINENT DESIGN FEATURES

BASIC PERFORMANCE
- DESIGN RANGE
- DESIGN PAYLOAD
- MAXIMUM STRUCTURAL PAYLOAD
- CRUISE MACH NUMBER

GROUND INTERFACE
- CARGO-COMPARTMENT FLOOR HEIGHT
- LOADING/UNLOADING APERTURES
- VEHICLE LOADING/UNLOADING MECHANISM
- CONTAINER/PALLET LOADING/UNLOADING SYSTEM
- AIR DROP PROVISIONS
- LOADING STABILIZER STRUTS
- GROUND REFUELING PROVISIONS

AIRFIELD COMPATIBILITY
- TAKEOFF DISTANCE
- LANDING GEAR FLOTATION
- RUNWAY WIDTH FOR 180° TURN
- NOISE CHARACTERISTICS

CARGO COMPARTMENT
- CARGO COMPARTMENT PLANFORM SHAPE
- CARGO ENVELOPE
- FLOOR STRENGTH
- SUB-FLOOR STRENGTH
- VEHICLE TIEDOWNS
- CONTAINER/PALLET HANDLING/RESTRAINT SYSTEM
- PRESSURIZATION
- CARGO-STICK WIDTH
- CARGO-COMPARTMENT LENGTH

INFLIGHT REFUELING
- INFLIGHT REFUELING TECHNIQUE
- TANKER KIT PROVISIONS

PERSONNEL ACCOMMODATIONS
- RELIEF-CREW PROVISIONS
- PASSENGER PROVISIONS

MISCELLANEOUS
- MAINTENANCE/SUPPORT CONCEPT
- AVIONICS
- SUBSYSTEM MOTIVE POWER

MILITARY/CIVIL DESIGN CRITERIA
- NOISE REGULATIONS
- ENGINE EMISSIONS REGULATIONS
- PERFORMANCE SPECIFICATIONS
- CERTIFICATION PROCEDURE
- DESIGN LIMIT-LOAD FACTOR
- SERVICE-LIFE SPECIFICATION

CRUISE MACH NO.	0.78
DESIGN PAYLOAD	495,000 LB
DESIGN RANGE	4000 NM
OPERATING WEIGHT	543,000 LB
MAX GROSS WEIGHT	1,370,000 LB
ASPECT RATIO	10.5
WING LOADING	129.4 PSF
THRUST PER ENGINE	80,000 LB

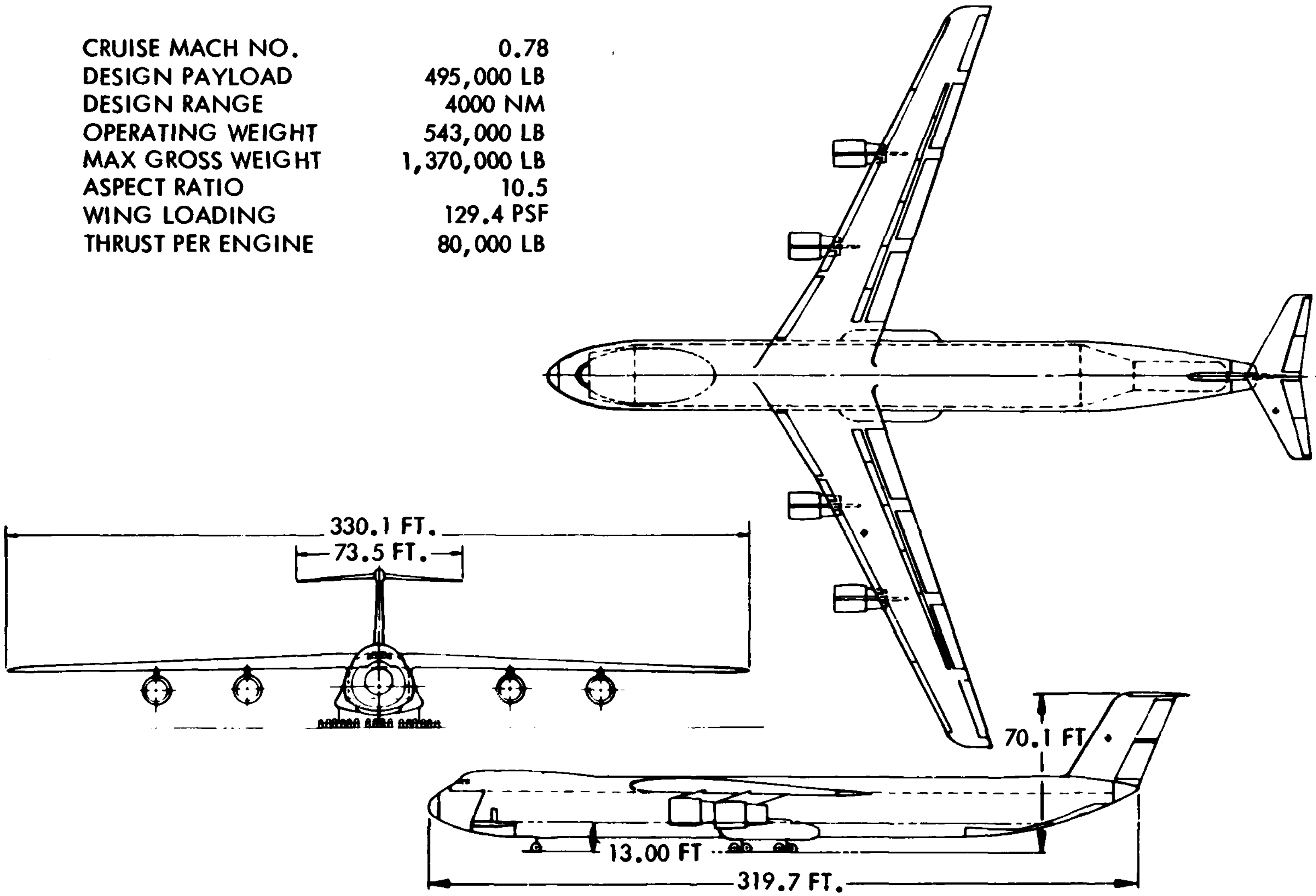


Figure 3. Baseline Aircraft General Arrangement

Other significant technology assumptions for the ACMA are in the fields of aerodynamics, propulsion, and stability and control. Application of super-critical airfoil technology permits thicker wing sections, and hence lower wing weights, than would otherwise be possible. Propulsion technology corresponds to that of the Pratt and Whitney STF 477 advanced-technology turbofan engine, initially described in fuel conservation studies sponsored by NASA between 1974 and 1976. (Ref 11) This engine incorporates new fan, compressor, combustor, and turbine technologies, as well as advanced structures and active clearance control for higher efficiencies, lower fuel consumption, and improved deterioration rates. Design criteria for sizing the directional, lateral, and longitudinal control surfaces of the baseline aircraft are based on MIL-F-8785B; however, the horizontal tail incorporates relaxed-static-stability technology. Surface area requirements are derived from the control-power considerations associated with takeoff rotation, trim at the forward center-of-gravity limit, and engine-out characteristics, and they assume an automatic stability augmentation system.

ASSESSMENT TECHNIQUE

With the framework and context of the qualitative assessment established, the process of assessment can proceed as follows. For each design feature, the first step was to identify the militarily desirable design option, the commercially desirable option, and any potentially interesting compromises. Then, within each functional grouping, the list of options is examined to identify inconsistent combinations, identify potentially synergistic combinations, eliminate options representing little apparent civil/military conflict, and to combine options where appropriate. The available options for each fracture are then subjectively rated in terms of their potential for enhancing commonality--taking both military and commercial considerations into account.

Of the features listed in Table 2, 16 survived the above-described initial assessment. These in turn were examined for interdependencies and inconsistencies in a final assessment.

As a result of this final assessment, 13 design features were identified and developed into four groups. This minimizes the effects of the interdependencies and permits periodic redefinition of the baseline aircraft after the Group I and again after the Group II analyses, thereby making best use of the study resources. The final list of design features for the detailed analysis is given in Table 3, divided into the four groups. The starred items are those given special attention at the request of the Air Force Study Manager. (Volume III of this final report describes the qualitative assessment in detail.)

The design features listed in Table 3 are not the only ones with an impact on military/commercial commonality; however, analysis of other features can be deferred until after these initial design questions have been examined in detail. The design features covered here are listed again for the convenience of the reader at the back of this volume, on a fold-out page, with the appropriate options and the model numbers assigned to each of them.

TABLE 3

DESIGN FEATURES RECOMMENDED FOR DETAILED ANALYSIS

- GROUP I
  - DESIGN PAYLOAD ★
- GROUP II
  - LOADING/UNLOADING APERTURES ★
  - PLANFORM SHAPE OF CARGO COMPARTMENT
  - FLOOR HEIGHT ★
- GROUP III
  - TAKEOFF DISTANCE/GEAR FLOTATION
  - NOISE CHARACTERISTICS/ENGINE-OUT CLIMB GRADIENT
- GROUP IV
  - CARGO ENVELOPE (MAXIMUM HEIGHT) ★
  - PASSENGER PROVISIONS ★
  - MAXIMUM STRUCTURAL PAYLOAD
  - SERVICE-LIFE SPECIFICATION
  - PRESSURIZATION ★

III. OVERVIEW OF DETAILED ANALYSES

The detailed analyses in this effort focus on what are thought to be, based on the qualitative assessment, the most significant design features and associated options. This section presents an overview of the methodology used to perform these detailed analyses, highlighting the format used to present the data.

ANALYTICAL APPROACH

Figure 4 presents our approach to the detailed analyses. The first step is configuration development in which the option being investigated is incorporated into the baseline configuration for that group. The purpose of the redesign is to take maximum advantage of incorporating the option, subject to the following special constraints:

- In the Group II analyses, design payload is allowed to change in increments of 15,000 pounds as container positions are made available by the redesign of the cargo compartment planform.
- In the Group IV analyses, the weight of integral passenger provisions are added to aircraft structure and furnishings, while the weight of the passengers themselves increase design payload over the Group IV baseline.
- Also in the Group IV analyses, when the option to reduce the baseline cargo compartment height is incorporated, aircraft parameters such as fuselage fineness ratio and rotation angle are held constant.

Of course, other more general constraints also apply to the redesign process, such as maintaining constant technology levels.

The next step in the detailed analyses is the resizing of the modified baseline aircraft. This is accomplished utilizing the computer codes described in Appendix B in which the major aircraft components are iteratively sized within the program to allow the aircraft to accomplish the design mission at the minimum gross weight.

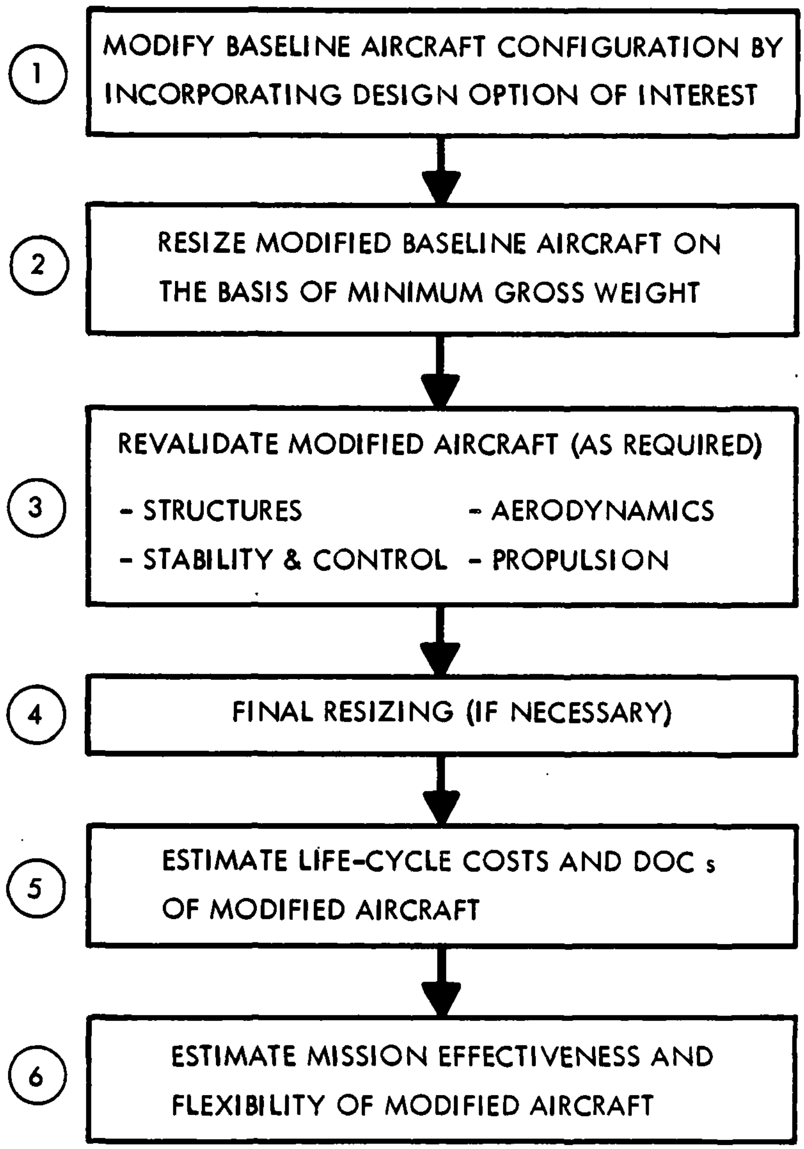


Figure 4. Analytical Approach for the Detailed Investigation of Design Options

The resizing process is followed by a revalidation of the new aircraft by specialists in areas such as structures, aerodynamics, stability and control, and propulsion. Special attention is paid to the inputs and resulting effects related to the option being investigated. If necessary, a final resizing run is made to incorporate recommendations from the specialists.

At that point, a fully defined, point-design aircraft is available for further analysis. A general arrangement drawing is prepared for those significantly different configurations. Value engineering specialists then make inputs to help develop both military and commercial costs for each point design. Maintainability and reliability specialists make estimates based on the actual point-design configuration to lend more accuracy to the final cost analysis. They also provide inputs into the effectiveness analyses; other aircraft-related inputs include cargo compartment and aircraft/airfield interface parameters.

The organization of this report places the discussion of the methodologies and detailed results in the appendices, Volumes IV and V. This volume contains only summary results and comparisons.

FIGURES OF MERIT

In order to evaluate the various design options, several figures of merit were chosen on the basis of their usefulness in making meaningful summary comparisons. These include payload fraction, fuel economy, life-cycle cost, unit price, military effectiveness, commercial direct operating cost, and return on investment. Other figures of merit are used for certain design options where those listed above are not adequate; the ones listed here are used often enough in this report to justify explaining their significance in this section.

For comparisons from a military viewpoint, payload fraction is used as a physical measure of the overall efficiency of the design, and is the non-dimensional quotient of design payload divided by takeoff gross weight. Military life cycle costs are calculated as explained in Appendix G; military effectiveness is usually measured in terms of the rate at which the

point-design aircraft can move material required in the NATO scenario as defined by ANSER, in units of tons per day. However, several design features require other figures of merit to best present military effectiveness, and these are explained in the context in which they are used. Cost effectiveness is calculated only when the tons per day parameter is used.

For comparisons from the civil viewpoint, fuel efficiency was chosen as an appropriate physical parameter, while commercial unit price and direct operating costs are useful for economic comparisons. Unit price is calculated in accordance with Appendix G, while direct operating costs are derived from the design-point trip cost when divided by the available commercial payload in tons and the commercial range in nautical miles, yielding the units of cents per ton-nautical mile. The second measure of commercial economics is an attempt to reflect the necessity for an airline's revenue to not only cover operating costs but also to provide for a reasonable return on investment. This is accomplished by taking 15 percent of the point-design aircraft's acquisition cost, dividing that number by the number of trips it would make per year, and adding it to DOC to obtain a new measure which will be called DOC+ROI, also in units of cents per available ton-nautical mile.

The next four sections of this report use these measures, as well as present a summary of the supporting data, to describe the analysis of each of the four groups.

IV. GROUP I SUMMARY RESULTS

The Group I analyses are devoted exclusively to the design payload feature. The design payloads examined are determined by starting with the LGA-144-100 baseline payload of 495,000 pounds and decrementing 45,000 pounds at a time to 315,000 pounds, giving the payloads shown on the foldout page at the back of this volume. This is accomplished with a constant cross-section shape and a constant floor loading, as discussed in the Qualitative Assessment, Volume III. For each successive option, 20.25 feet are removed from the fuselage constant section, thus deleting three container positions. Each new fuselage is input to the optimization code, which resizes the wing, engines, and empennage to the original mission, resulting in new point-design aircraft.

The model numbers used in this report all have the basic LGA-144 designation and will be referred to by their dash numbers from this point on. We recommend the reader unfold the page at the back of this volume so that it is readily available for reference in the following discussions.

CONFIGURATION COMPARISONS

The Group I point designs are described in detail in Appendix C; however, Figure 5 compares the -100 baseline with the smallest Group I aircraft, the -114. The visual impressions of considerable change in dimensions are confirmed by Table 4, which compares the major weight items for all the Group I aircraft. Note that the gross weight is reduced by almost half a million pounds, going from the largest to the smallest design payload. However, if fuel, operating weight, and payload are "normalized" by dividing by the gross weight of each option, some trends can be noted. Figure 6 presents these data in terms of percent change relative to the -100 baseline. Fuel fraction shows an advantage for the larger aircraft, reflecting economies of scale favoring it in an almost linear fashion. Operating empty weight fraction shows the opposite trend, favoring the smaller aircraft. Payload fraction, however, has a very weak optimum around 450,000 pounds of payload for this three-stick cross section, although the total change is only about one percent.

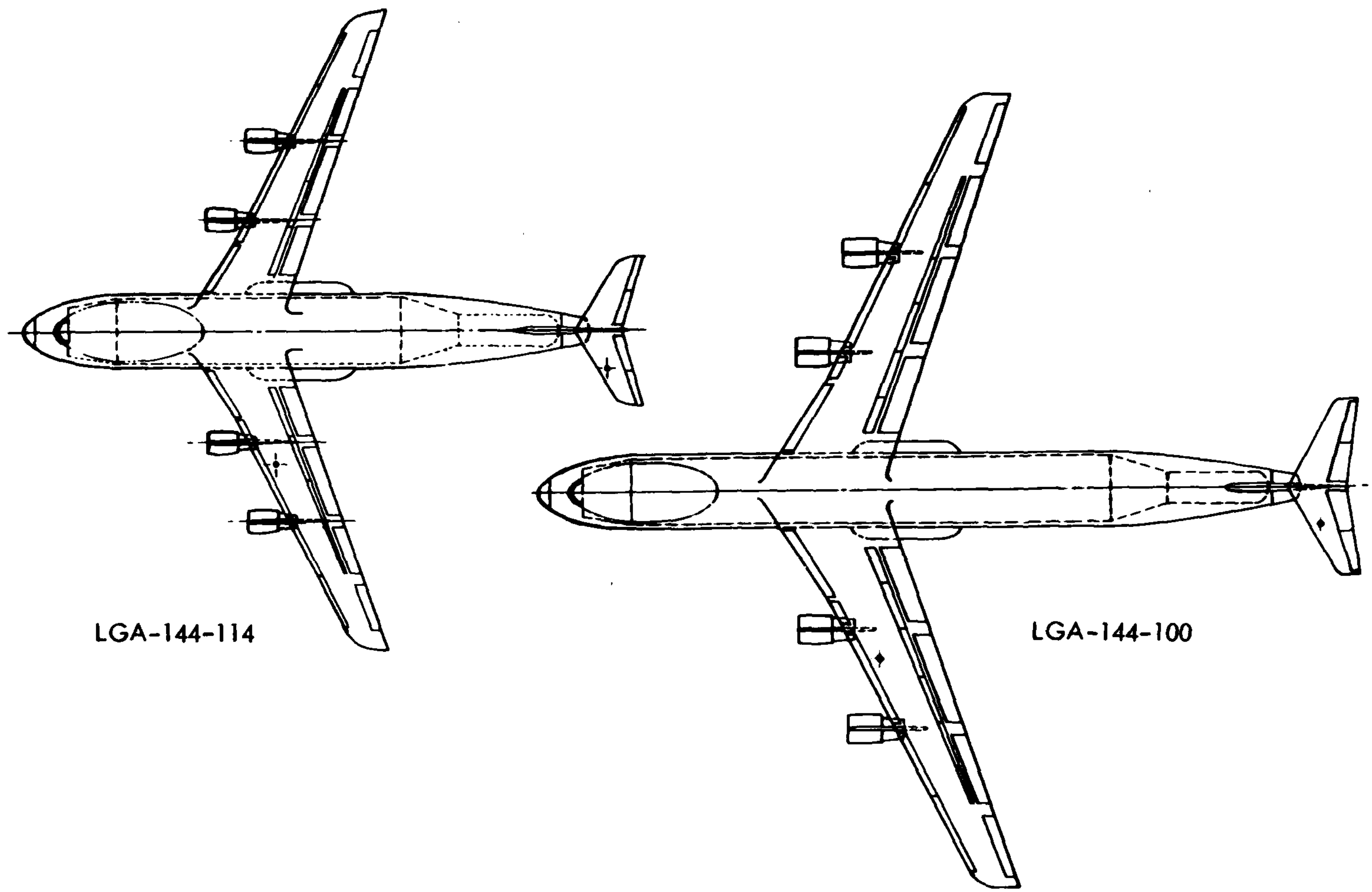


Figure 5. Comparison of Group I Aircraft

TABLE 4
GROUP I WEIGHT COMPARISON
(THOUSANDS OF POUNDS)

	MODEL NUMBER				
GROUP WEIGHT	-100	-111	-112	-113	-114
STRUCTURE	412.6	370.5	329.7	290.3	252.4
PROPULSION	73.6	66.6	59.9	53.4	47.1
SYSTEMS & EQUIPMENT	40.4	38.4	36.5	34.5	32.5
WEIGHT EMPTY	(526.6)	(475.6)	(426.1)	(378.3)	(332.0)
OPERATING EQUIPMENT	16.8	15.0	13.3	11.7	10.2
OPERATING EMPTY WEIGHT	(543.3)	(490.6)	(439.4)	(390.0)	(342.2)
PAYLOAD	495.0	450.0	405.0	360.0	315.0
ZERO FUEL WEIGHT	(1,038.3)	(940.6)	(844.4)	(750.0)	(657.2)
FUEL	332.1	303.7	276.0	248.7	221.8
GROSS WEIGHT	(1,370.5)	(1,244.3)	(1,120.4)	(998.7)	(879.0)
AMPR WEIGHT	444.5	401.5	359.8	319.4	280.5

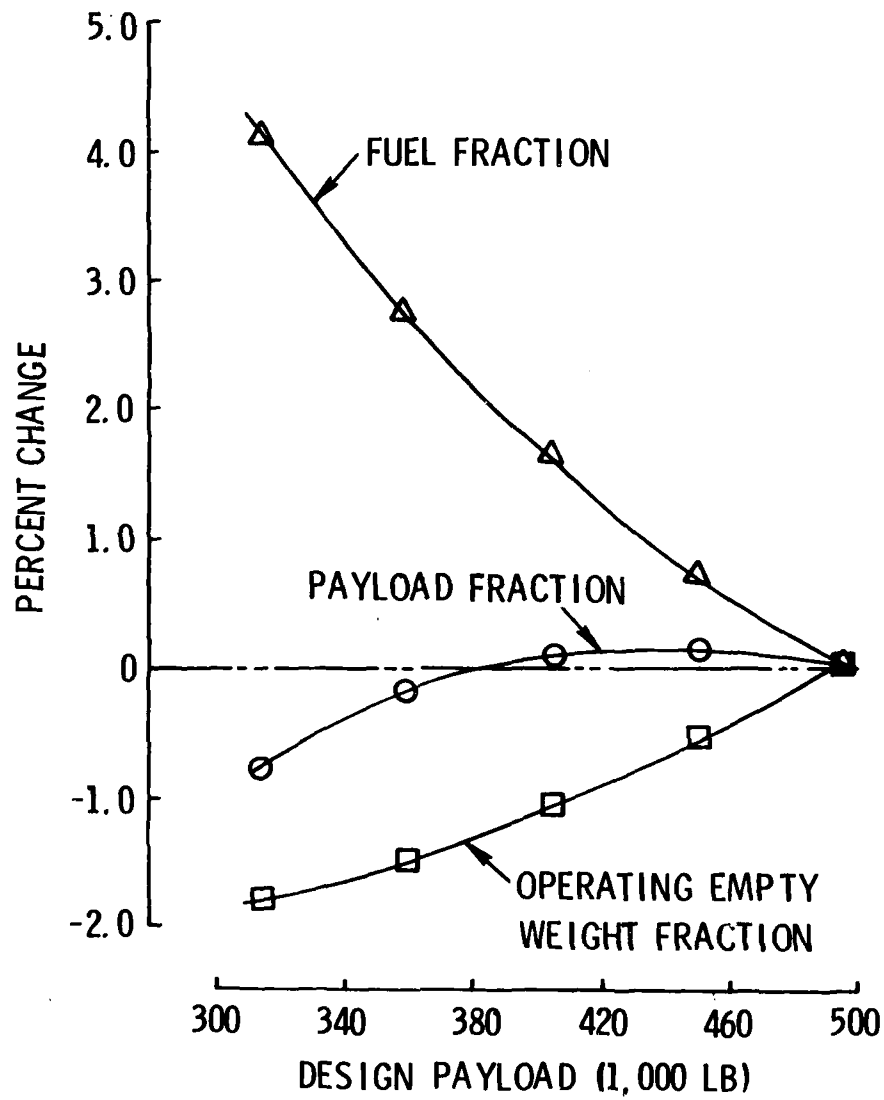


Figure 6. Relative Change in Weight Fractions

COST COMPARISONS

The Group I military cost analyses, summarized in Table 5, compare fleets of each point design aircraft for both an all-military program and for a program where civil operators purchase one-half the production. (Unless otherwise noted, all cost estimates presented in this report are in constant FY 78 dollars.) The fleet size for the -100 baseline (200) is an estimate of the number of aircraft required in the ANSER scenario. For each of the options, fleet size is obtained by ratioing the baseline fleet size by the inverse ratio of the payload of the option to the baseline payload, which is a first approximation to maintain equal productivity fleets. The CRAF conversion kits are added to the military costs in the military/commercial program.

Examining these same costs in terms of percentage changes illustrates an important economic trend. Figure 7 shows that the all-military program costs strongly favor the smaller design payloads. But as commercial participation in the ACMA program increases, the smaller aircraft lose some of their disadvantages to the point where, for a two-thirds commercial buy (1/2), the military is indifferent to the payloads between 300,000 and 400,000 pounds. (The numbers in parentheses indicate the ratio of numbers of aircraft procured by each user.) This is because the number of CRAF conversions kits has increased enough at the lighter payloads, due to the larger fleet sizes, to be a significant part of military life-cycle costs.

Commercial versions of the point design aircraft in this study are derived from the military versions in accordance with Table 6 and Figure 8. The -100 baseline is used to illustrate the weight changes; Table 6 shows the items that are deleted from the military operating weight empty (OWE) to obtain the commercial OWE. Fuel reserves are based on FAR international rules for a 3500 nautical mile mission, as represented by Figure 8. Payload thus becomes a fallout to bring the commercial version weight up to the original military gross weight. This process is required for input to the commercial cost analysis. Results for the Group I aircraft are given by Table 7 which show large variations in unit price in absolute terms. However, in terms of price per unit payload, the variation is much smaller, although it still favors the smaller aircraft.

TABLE 5
GROUP I COST COMPARISON

	MODEL NUMBER				
	-100	-111	-112	-113	-114
TOTAL NUMBER OF AIRCRAFT	200	220	244	275	314
ALL MILITARY PROGRAM					
RDT&E	4.0	3.7	3.5	3.2	2.9
PROCUREMENT	24.1	23.5	22.8	22.3	21.6
20-YEAR O&S	34.3	33.8	33.6	33.9	34.1
LIFE-CYCLE TOTAL	(62.4)	(61.0)	(59.9)	(59.3)	(58.7)
MILITARY/COMMERCIAL PROGRAM (1/1 RATIO)					
RDT&E	2.0	1.9	1.7	1.6	1.5
PROCUREMENT	12.0	11.7	11.4	11.1	10.8
20-YEAR O&S	17.2	16.9	16.8	16.9	17.1
CRAF CONVERSION KITS	0.4	0.5	0.7	0.8	1.0
LIFE-CYCLE TOTAL	(31.6)	(31.1)	(30.6)	(30.5)	(30.3)

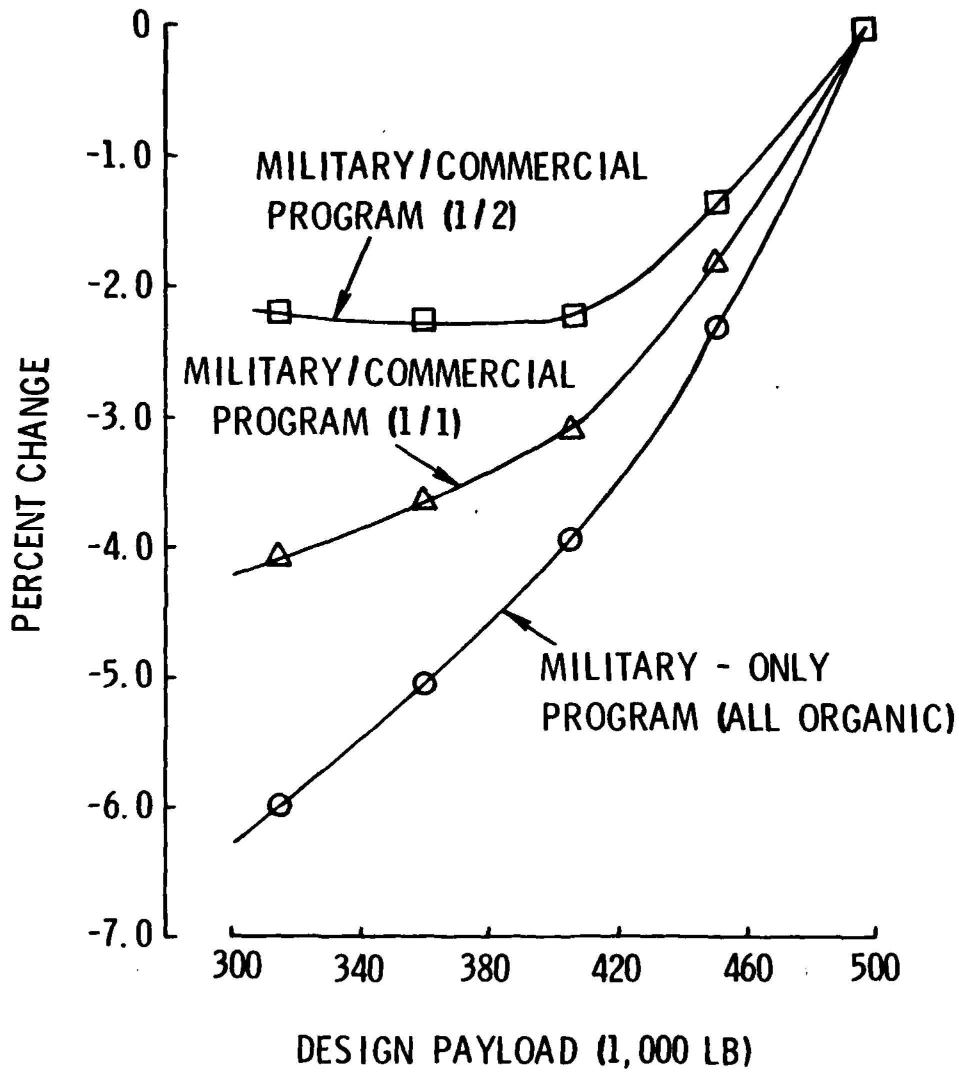


Figure 7. Relative Change in Military Life-Cycle Cost

TABLE 6

WEIGHT CHANGES FOR COMMERCIAL VERSION LGA-144-100

ITEM	WEIGHT (LB) -100C	WEIGHT (LB) -100T
LGA-114-100 OPERATING EMPTY WEIGHT	543,339	543,339
RAMPS	-15,110	-
RELIEF-CREW FURNISHINGS	-700	-
CARGO WINCH	-340	-
LOADING STABILIZER STRUTS	-430	-
AERIAL REFUELING RECEPTACLE	-120	-
TANKER - KIT SCAR WEIGHT	-1,470	-
TANKER KIT	-	+5,360
TIEDOWN EQUIPMENT	-7,420	-
TIEDOWN RINGS	-1,610	-
LOADMASTERS	-440	-
OPERATING EMPTY WEIGHT	(515,699)	(548,699)
MAXIMUM PAYLOAD	522,640	0
ZERO FUEL WEIGHT	(1,038,339)	(548,699)
FUEL	332,138	821,778
MAXIMUM GROSS WEIGHT	(1,370,477)	(1,370,477)

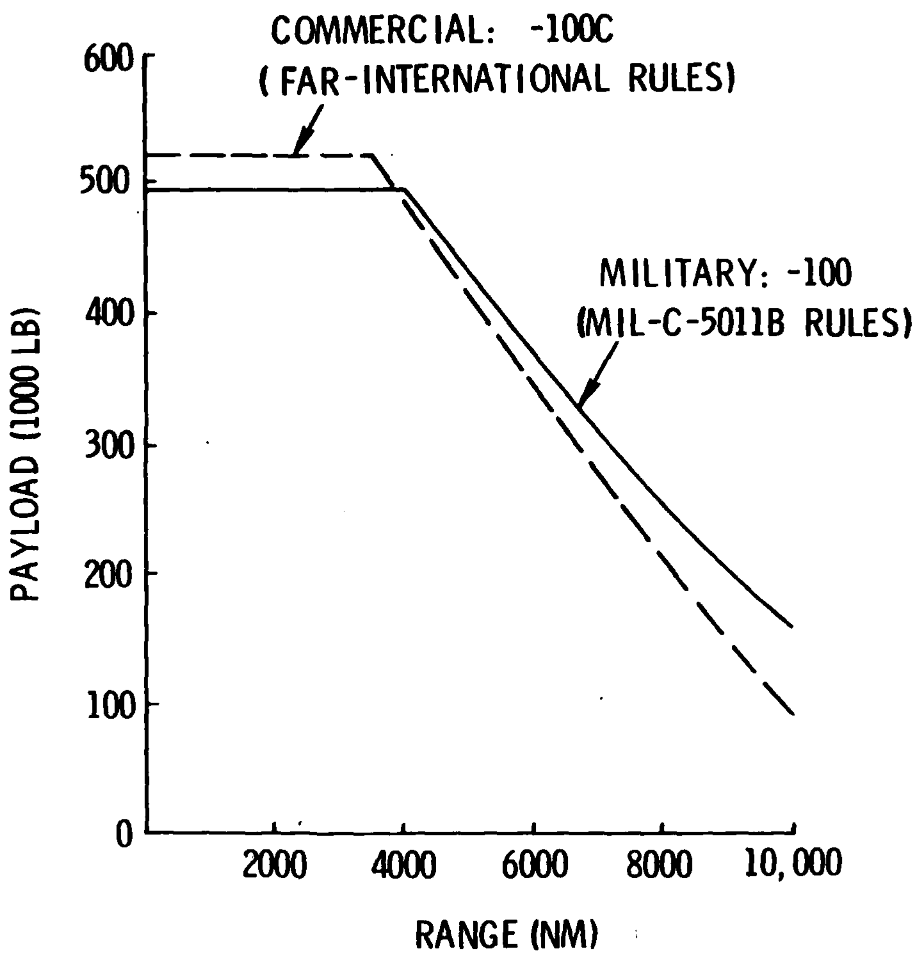


Figure 8. Payload-Range Comparison

TABLE 7
GROUP I COMMERCIAL UNIT PRICES

- COMMERCIAL UNIT PRICE

MODEL NUMBER	PRICE ($ MILLION) ABSOLUTE	PRICE ($ MILLION) PER TON OF PAYLOAD
-100C	116.4	0.470
-111C	101.8	0.452
-112C	88.2	0.436
-113C	74.9	0.416
-114C	62.6	0.398

- DIRECT OPERATING COSTS
  - MODIFIED 1967 ATA EQUATIONS
  - FUEL AT 50 CENTS PER GALLON (1978 DOLLARS)

Another important commercial economic measure is trip cost. Figure 9 compares total trip costs for a 4000-nautical-mile stage length across the range of Group I payloads. The total trip cost is broken into its major elements to show those sensitive to payload changes. When trip costs are divided by the productivity of the aircraft, the result is the direct operating cost comparison in Figure 10. The data are again presented in terms of percent change relative to the -100 baseline and shows an optimum at about 360,000 pounds of payload.

MILITARY EFFECTIVENESS

An analysis of the military effectiveness of these design payload options also provided some interesting results. The deployment rate, when plotted in the percent change format in Figure 11, shows that the smaller aircraft are more effective than the baseline, although this result is primarily driven by the fleet size assumptions. The curve does imply that the 315,000-pound payload aircraft is more effective than the 360,000-pound for current Army divisions. This situation changes when the projected Army equipment of the 1990s is considered. Figure 12 shows that, for the current H-Series TOE, the -114 does have a higher average utilized payload than the -113. When considering future Army equipment the presence of heavier equipment, especially the XM-1 Tank, reverses the advantage in favor of the -113. Thus, for the army of the 1990s, the 360,000-pound payload option is more attractive.

SUMMARY COMPARISONS

A summary of the results of the Group I analysis is given by Table 8. The -100 baseline is compared to the 360,000-pound payload -113 aircraft, which we believe is the best alternative for design payload. Generally the smaller design payloads are preferred from both the military and commercial viewpoints, although there are only small variations in most figures of merit. For the military, however, the 360,000-pound payload does ensure that three XM-1 Tanks can be carried for the design range.

At this point in the study, a new baseline configuration was required for the Groups II and III analyses. The -113 was selected and approved by the Air Force Study Manager on 16 January 1979.

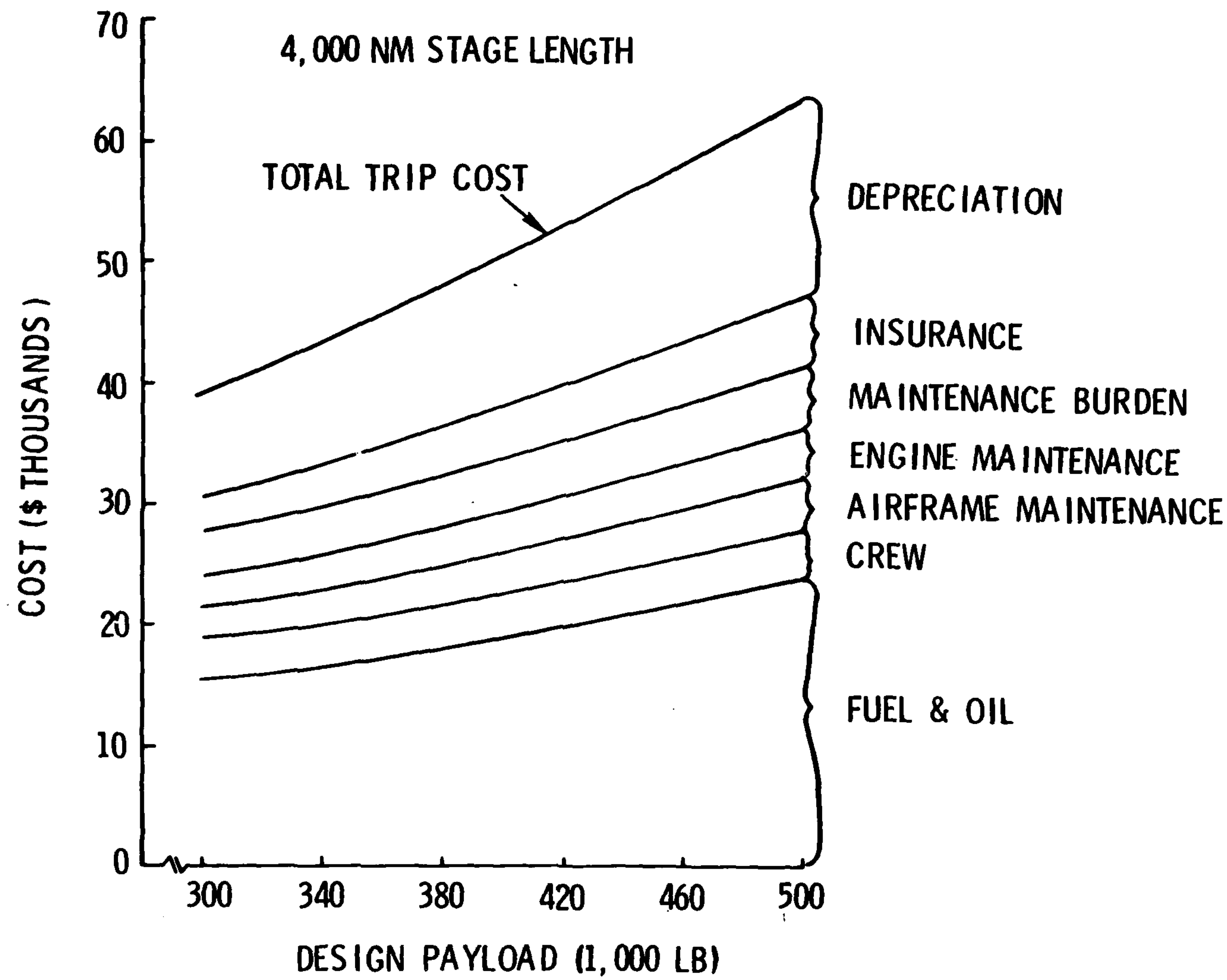


Figure 9. Group I Trip Cost Comparison

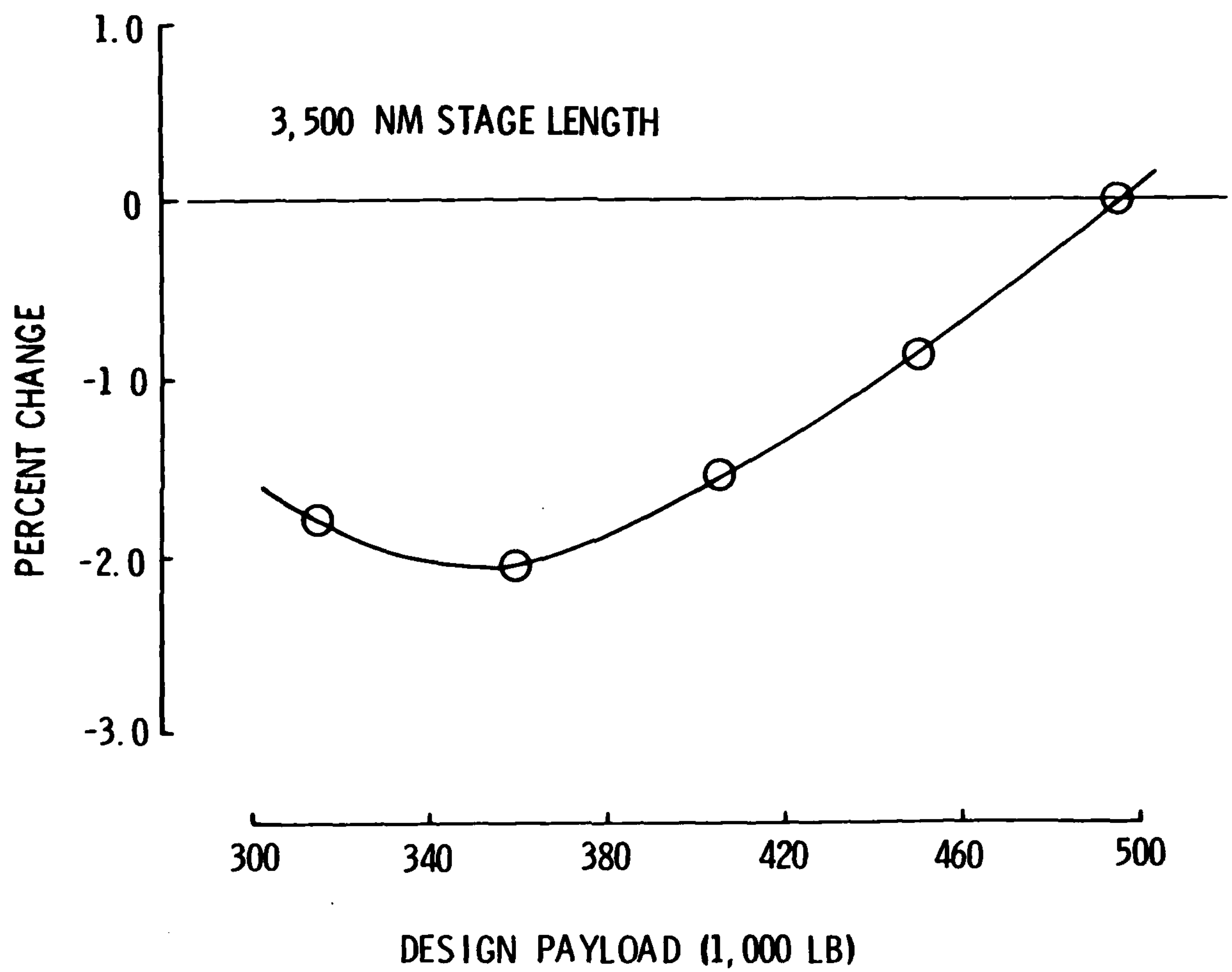


Figure 10. Relative Change in Group I DOCs

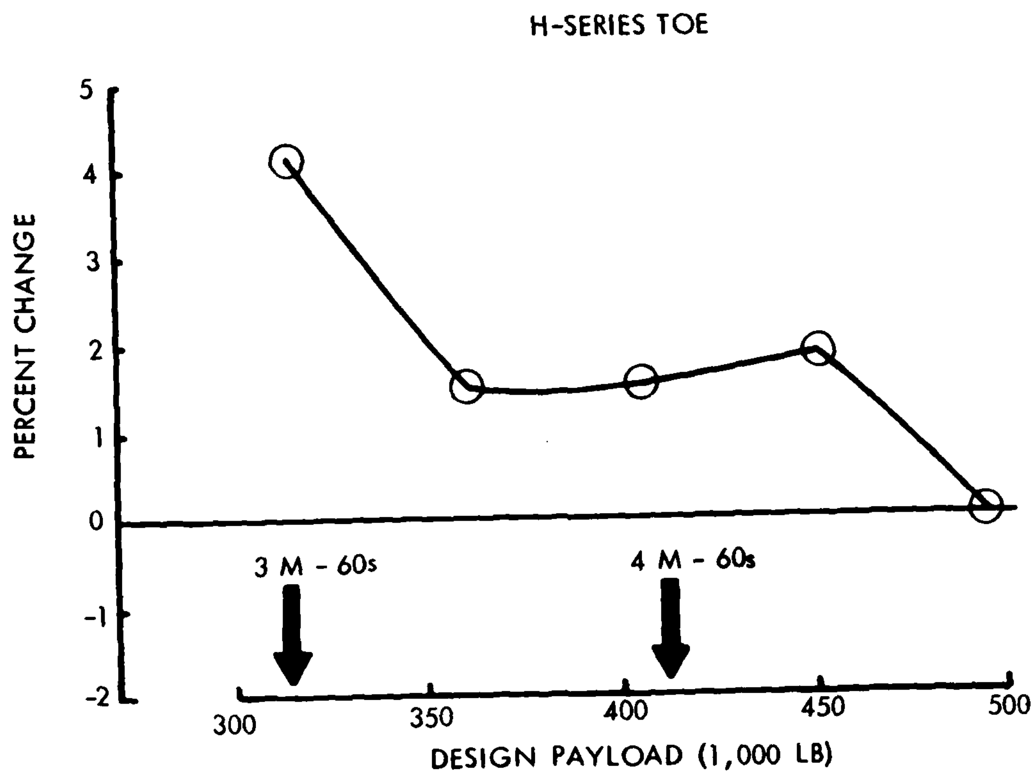


Figure 11. Relative Change in Deployment Rate

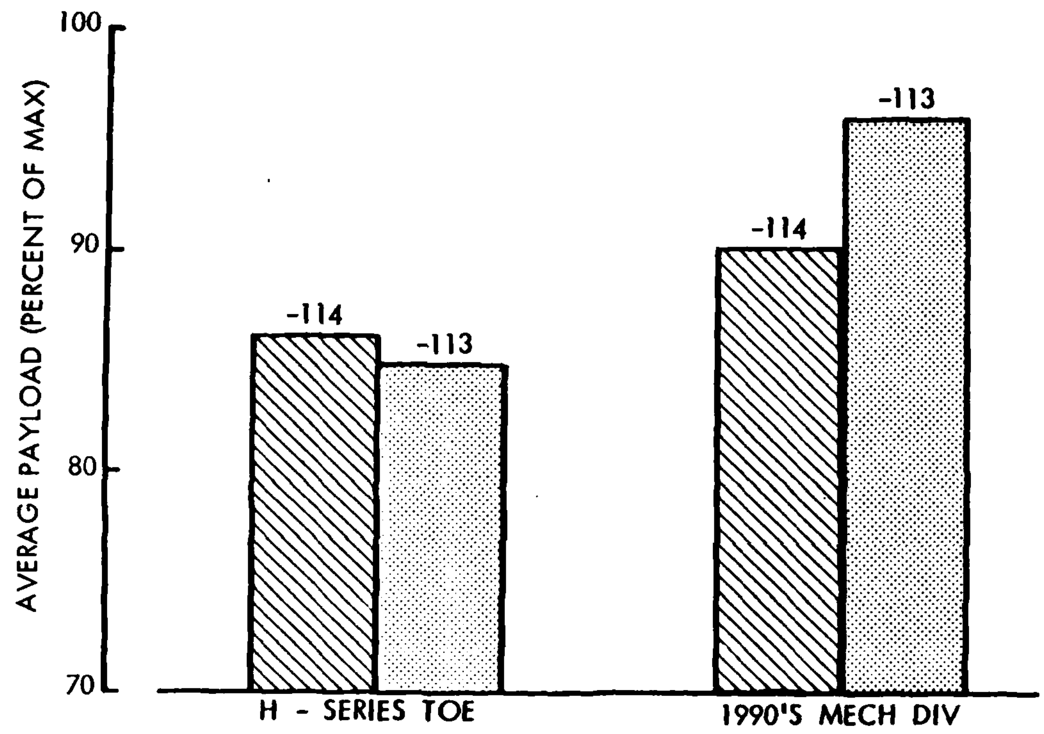


Figure 12. Effect of Division Restructuring on Design Payload

TABLE 8

DESIGN PAYLOAD SUMMARY COMPARISON

MODEL NUMBER	LGA-144-100	LGA-144-113	LGA-144-113
Design Payload	495,000 Lb	360,000 Lb	360,000 Lb
TOTAL NUMBER OF AIRCRAFT	200	275	+37.5%
MILITARY			
Payload Fraction	0.3612	0.3605	-0.2%
Life-Cycle Costs ($ Bil)	32.0	30.5	-4.8%
NATO Effectiveness (Tons/Day)	23,200	23,300	+0.3%
Cost-Effectiveness ($ Mil/Tons/Day)	1,379	1,309	-5.0%
COMMERCIAL			
Fuel Economy (TNM/Gal)	22.2	21.8	-1.6%
Unit Price ($ Mil)	116.4	74.9	-35.7%
DOC (¢/ATNM)	6.06	5.93	-2.1%
DOC + ROI (¢/ATNM)	10.21	9.57	-6.3%

V. GROUP II SUMMARY RESULTS

The Group II analyses focus on some of the aspects of cargo aircraft design which have the greatest impact on the configuration once the cross-section and overall length have been selected. As shown on the foldout page, these aspects are the location and size of the doors, the taper of the cargo floor planform, and the decision whether to provide the landing gear with a kneeling capability.

The baseline for Group II, the LGA-144-200 shown in Figure 13, is the result of the selection in Group I of the 360,000-pound payload, and a decision to retain the rolling stock, including wheels, tires and brakes, of the LGA-144-100. This ensures that the -200 can be classified as having Load Classification Group (LCG) III landing gear flotation at takeoff gross weight. A more complete description of the -200 is given in Appendix D.

The options to the Group II design features were logically combined to form the list in Table 9. The -200 baseline has apertures at the front and rear of the aircraft and a cargo floor tapered in planform at both ends. The -211 has only a front door and a cargo floor tapered forward and aft. The -221 has both front and rear doors, and is full-width for the complete length of the cargo compartment. The -222 has both front and rear doors, but is full-width forward and tapered aft. Finally the -223 has only the full-width forward door and a tapered floor aft. For the floor height design feature, the -231 has the cargo compartment arrangement of the -200 baseline, but does not have kneeling landing gear. A pictorial description of these options is shown in Figure 14.

NUMBER AND WIDTH OF APERTURES

Each of the options is subjected to analyses which leads to a point-design aircraft. This process is described in considerable detail for each model in Appendix D. The discussion in this volume will cover only the most significant aspects of this design process.

CRUISE MACH NO.	0.78
DESIGN PAYLOAD	360,000 LB
DESIGN RANGE	4,000 NM
OPERATING WEIGHT	400,000 LB
MAX. GROSS WEIGHT	1,011,000 LB
ASPECT RATIO	10.5
WING LOADING	129.4 PSF
THRUST PER ENGINE	59,000 LB

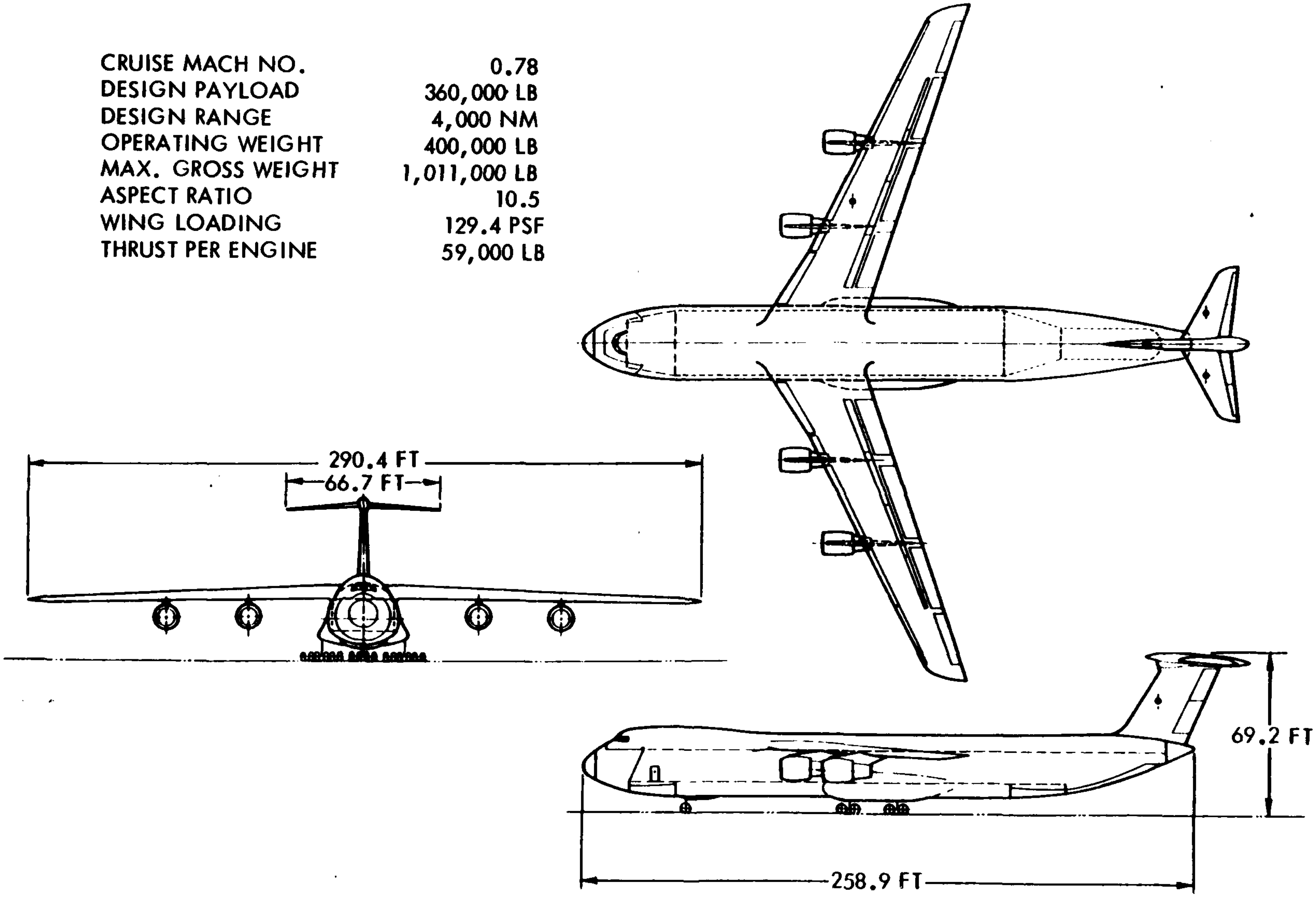


Figure 13. General Arrangement: LGA-144-200

TABLE 9
OPTIONS UNDER CONSIDERATION

MODEL NUMBER	FORWARD APERTURE	AFT APERTURE	KNEELING GEAR
LGA-144-200	19.5 FT WIDE	13 FT WIDE	YES
LGA-144-211	19.5 FT WIDE	NONE	YES
LGA-144-221	FULL WIDTH	FULL WIDTH	YES
LGA-144-222	FULL WIDTH	13 FT WIDE	YES
LGA-144-223	FULL WIDTH	NONE	YES
LGA-144-231	19.5 FT WIDE	13 FT WIDE	NO

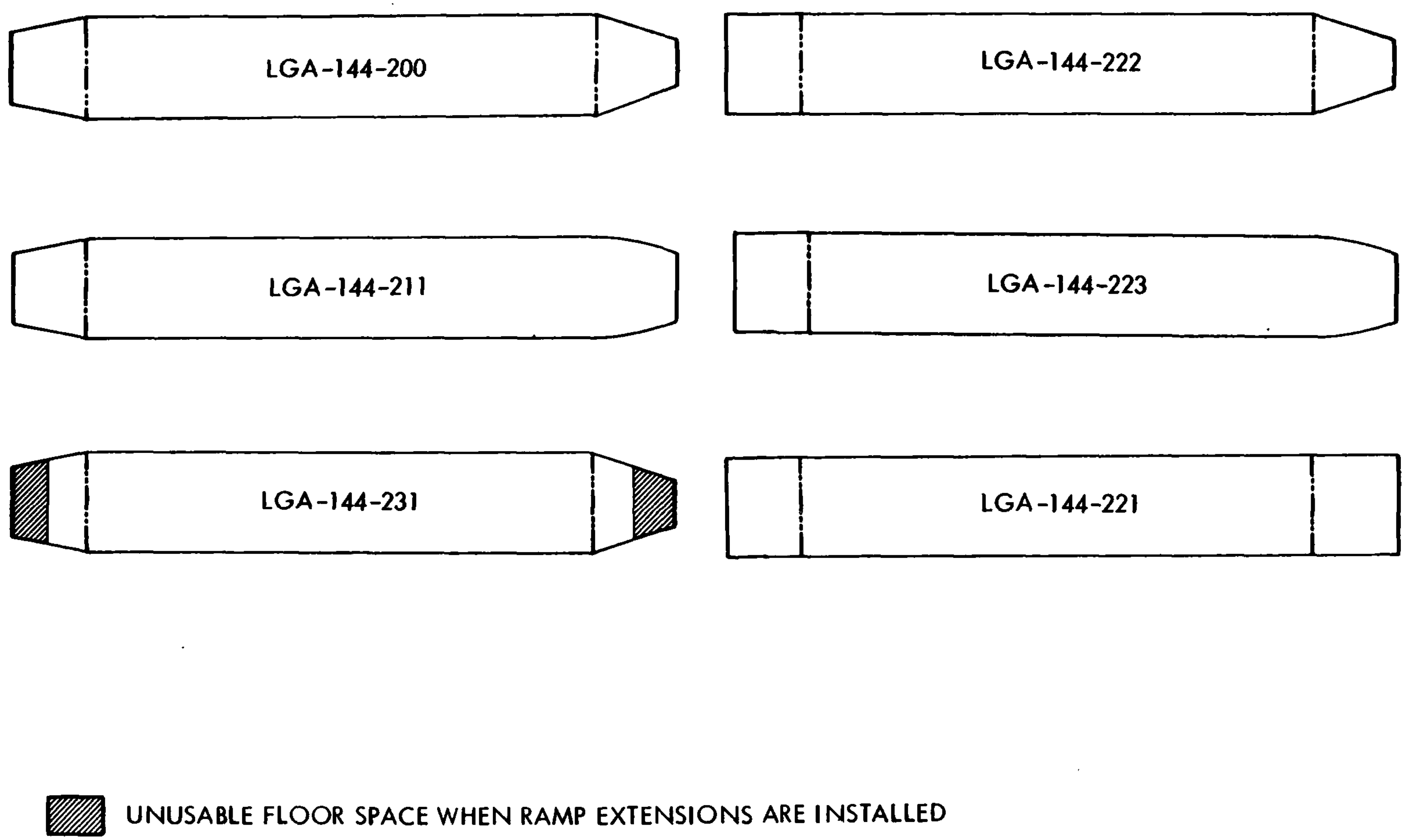


Figure 14. Cargo Compartment Planform Comparison for Group II Options

Some further information on the -200 baseline configuration is in order at this point. The baseline forward fuselage external geometry is shown in Figure 15. The tapered cargo compartment planform is a result of the forebody taper desired for the Mach 0.78 cruise speed requirement. The arrangement of the ramp and ramp extensions is shown in Figure 16. The effect of the taper, from 27.33 feet in the cargo compartment to 19.5 feet at the aperture, is especially apparent in the front view. This arrangement provides the same outsized-cargo loading capabilities as the Air Force C-5A.

The corresponding aft fuselage exterior and interior details are presented in Figures 17 and 18. The broad plan view shape and sharp upsweep angles are a result of the airdrop envelope and drive-on requirements.

The arrangement of containers in the -200 baseline cargo compartment is shown in Figure 19. Containers are arranged on the forward and aft ramps as space permits and require special roller and rail systems to properly guide the containers into their canted positions on the forward ramp.

Deletion of the Rear Aperture

The option to delete the rear aperture is incorporated in both the -211 and -223. The resulting cargo compartment planform for the -211 is depicted in Figure 20 compared to the -200 baseline. Note that the hinge line in the rear is deleted and the tapered floor area is larger than on the -200 because the aft part of the cargo-compartment is no longer a ramp, and full advantage can be taken of the available space to position two containers instead of just one as on the -200. This additional container increases the payload by 15,000 pounds, in accordance with the assumptions on container gross weight. This space is available despite the drastically altered aftbody shape for this option, as shown in Figure 21, because space which was wasted on the -200 because of its aft ramp can be efficiently used on the -211. Upsweep angle is considerably reduced, and the planform shape is allowed to taper naturally, matching the profile taper. Rotation angle is not changed. A comparison of the baseline and the new shape is shown on Figure 22. Since the fuselages are aligned at the rear of the constant section of the cargo box, the comparison emphasizes the reduced fuselage length.

MODEL NO. LGA-144-200

WETTED AREA:	21,730 FT^2
PRESSURIZED VOLUME:	148,167 FT^3
LENGTH OF FUSELAGE:	258.92 FT

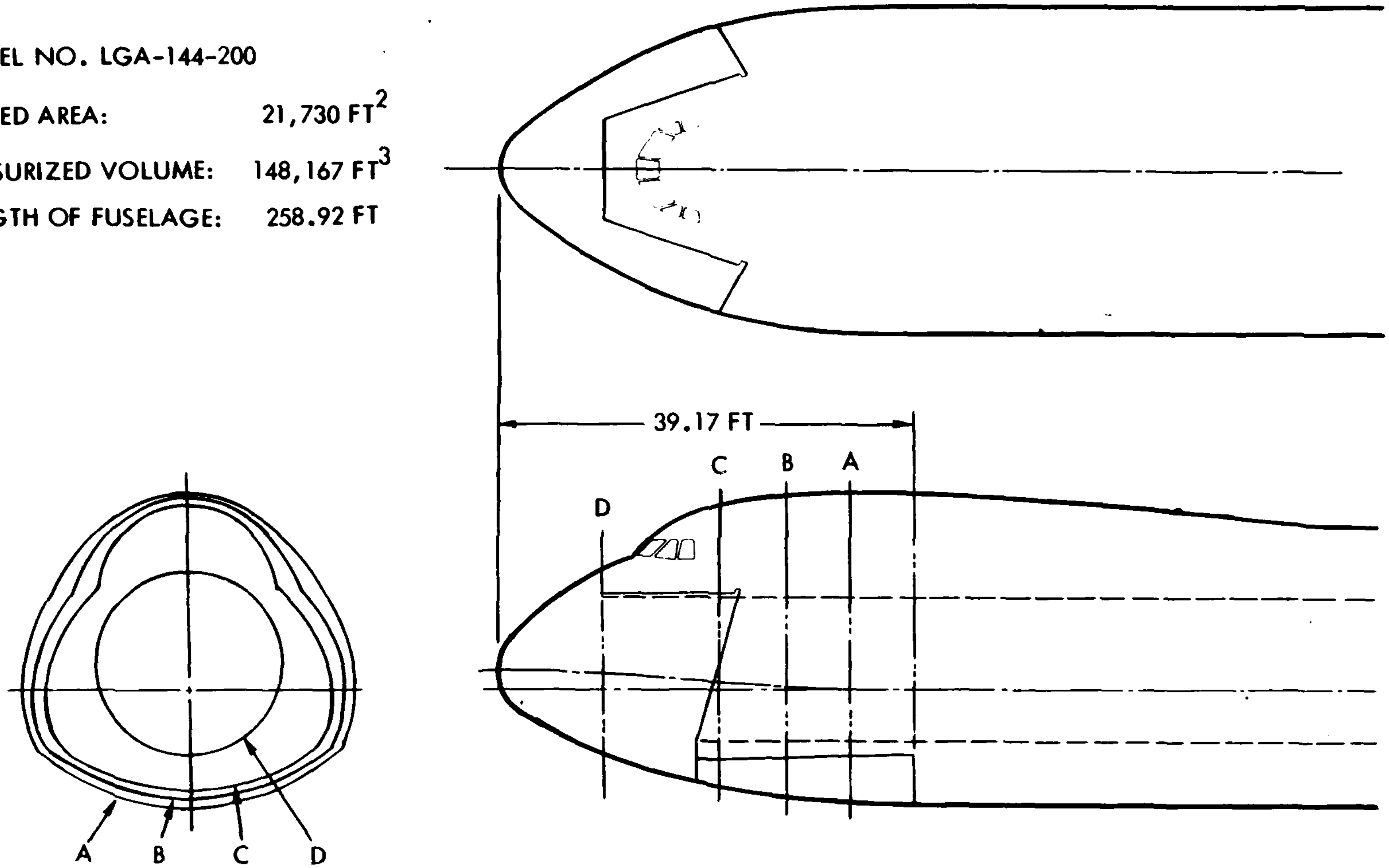


Figure 15. Baseline Forward Fuselage External Geometry

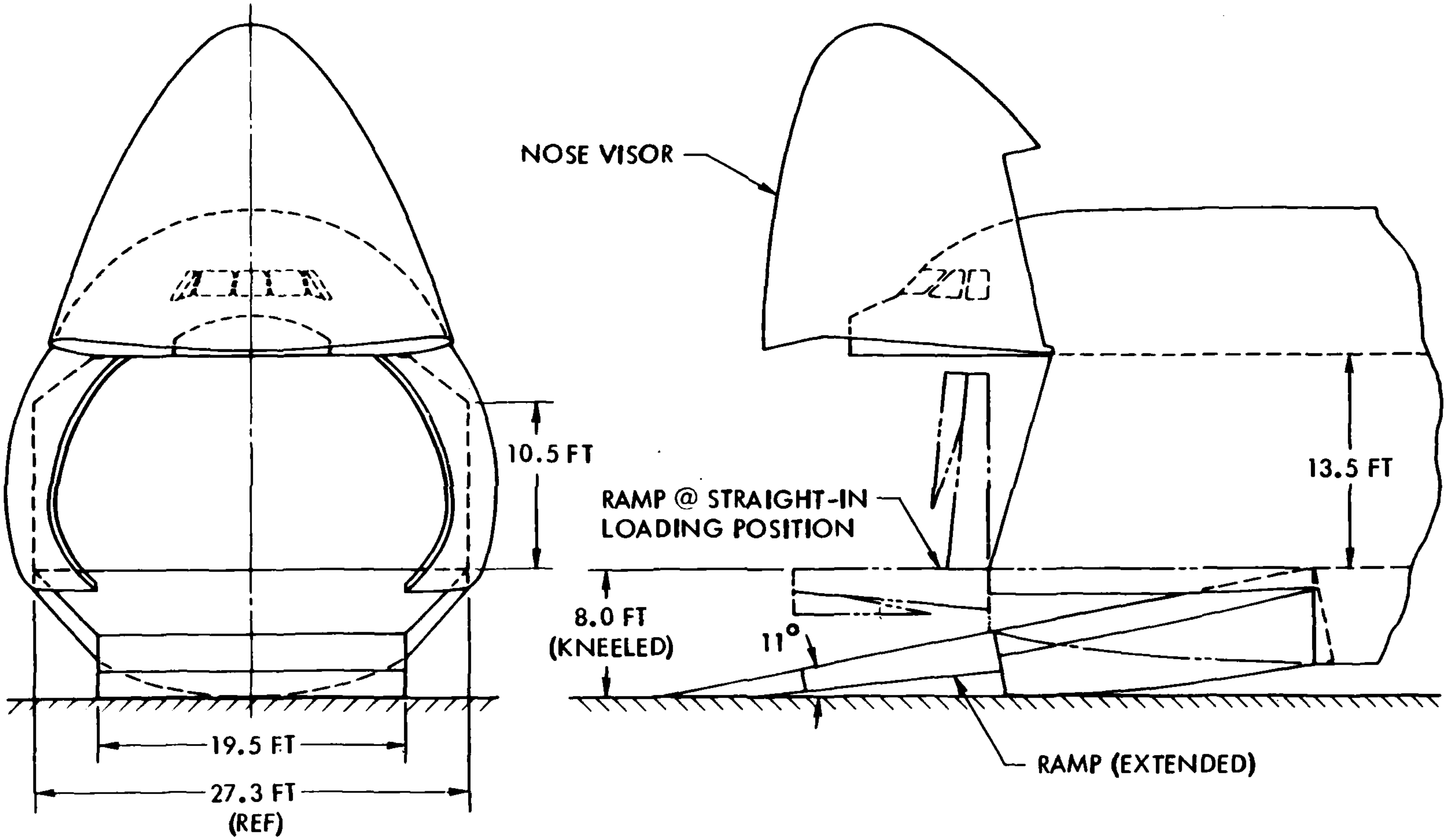


Figure 16. Baseline Forward Fuselage Interior Arrangement

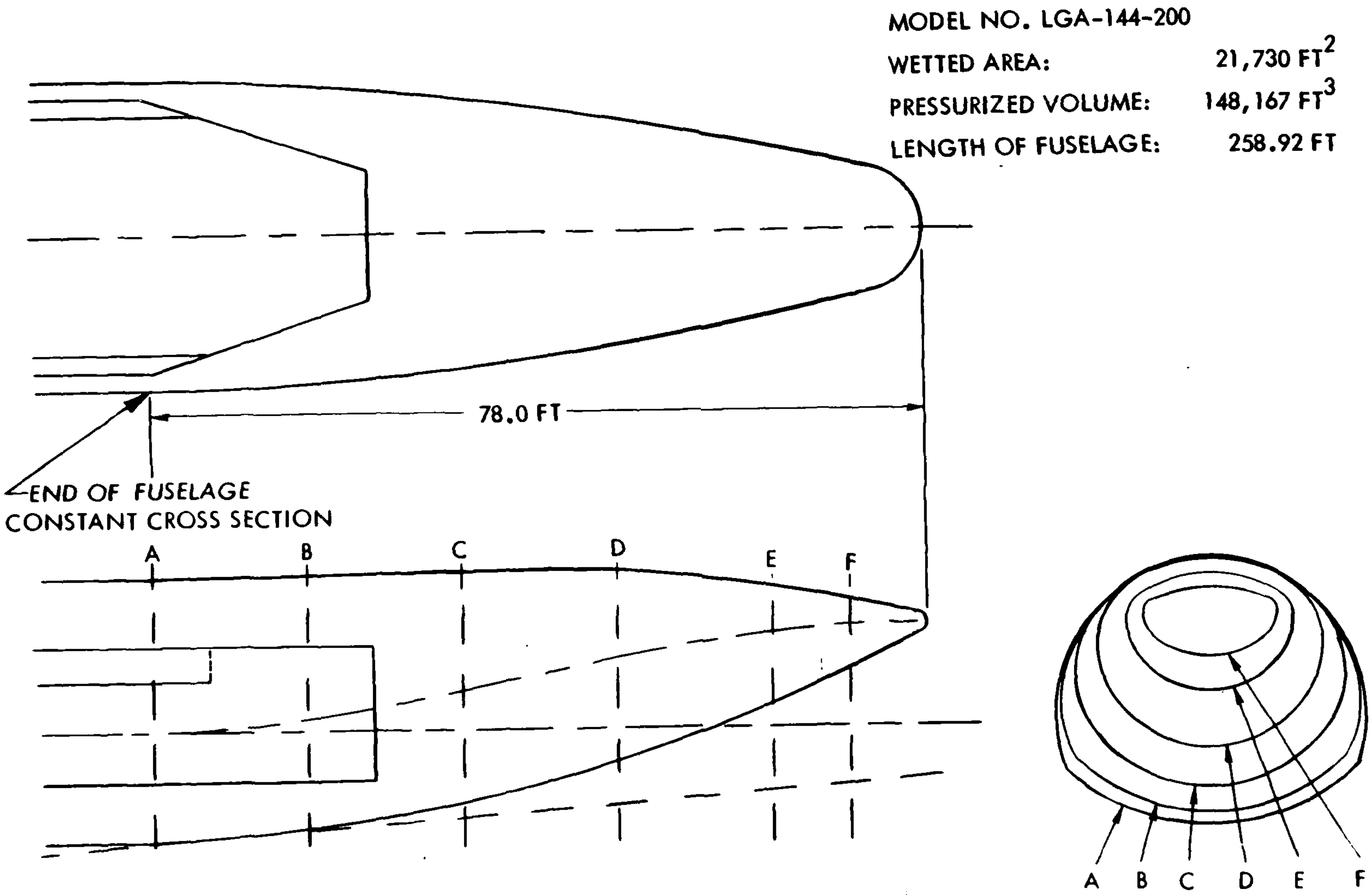


Figure 17. Baseline Aft Fuselage External Geometry

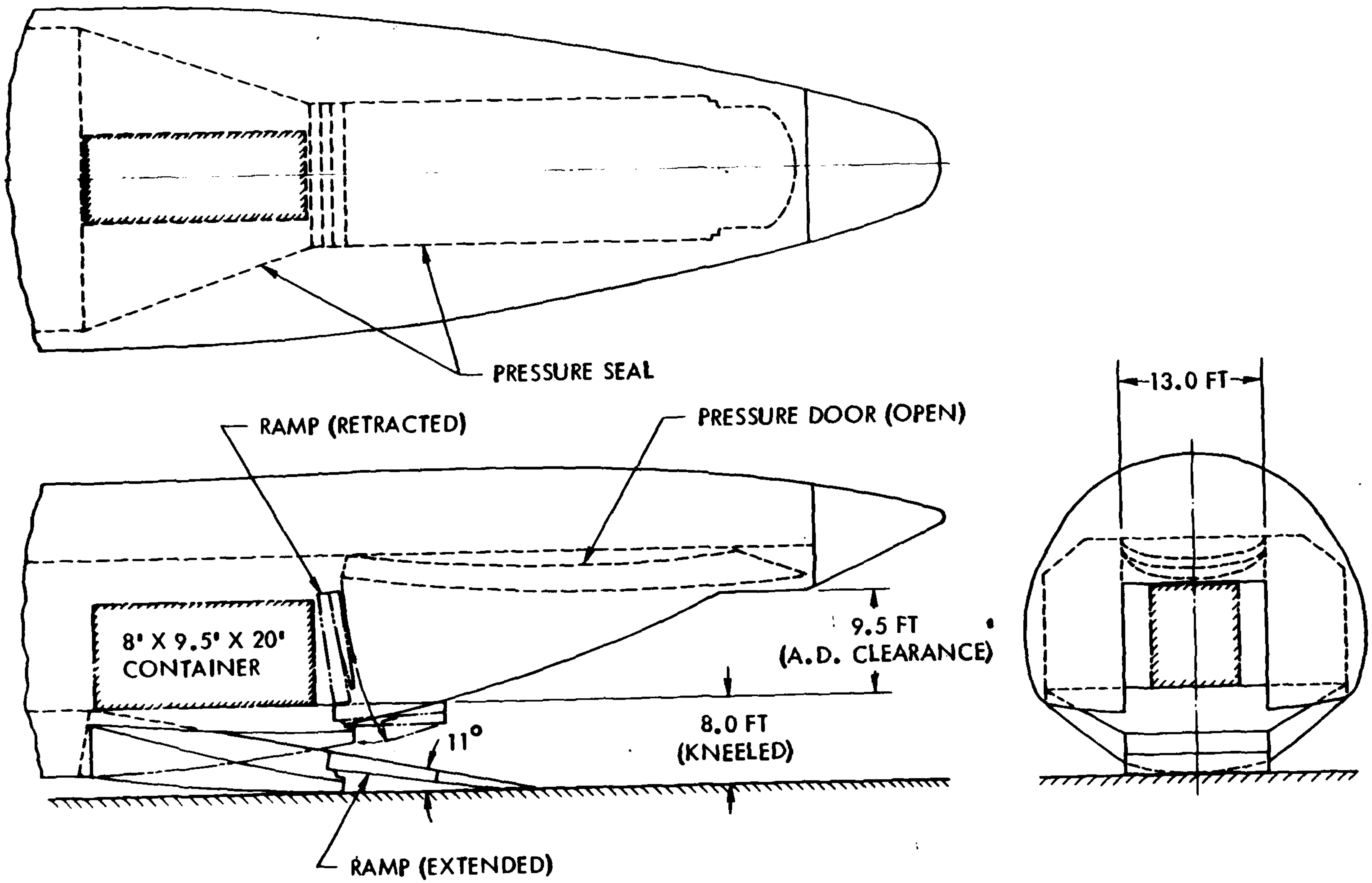
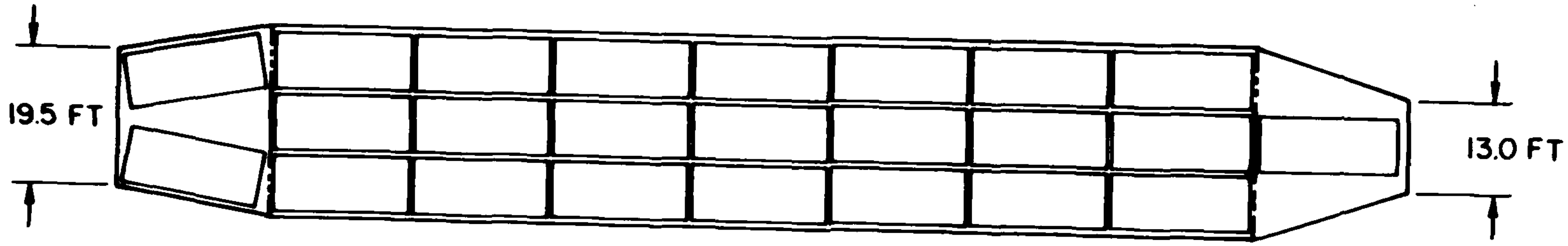


Figure 18. Baseline Aft Fuselage Interior Arrangement



24 X 15,000 LB = 360,000 LB PAYLOAD

Figure 19. Baseline Cargo Compartment Container Arrangement

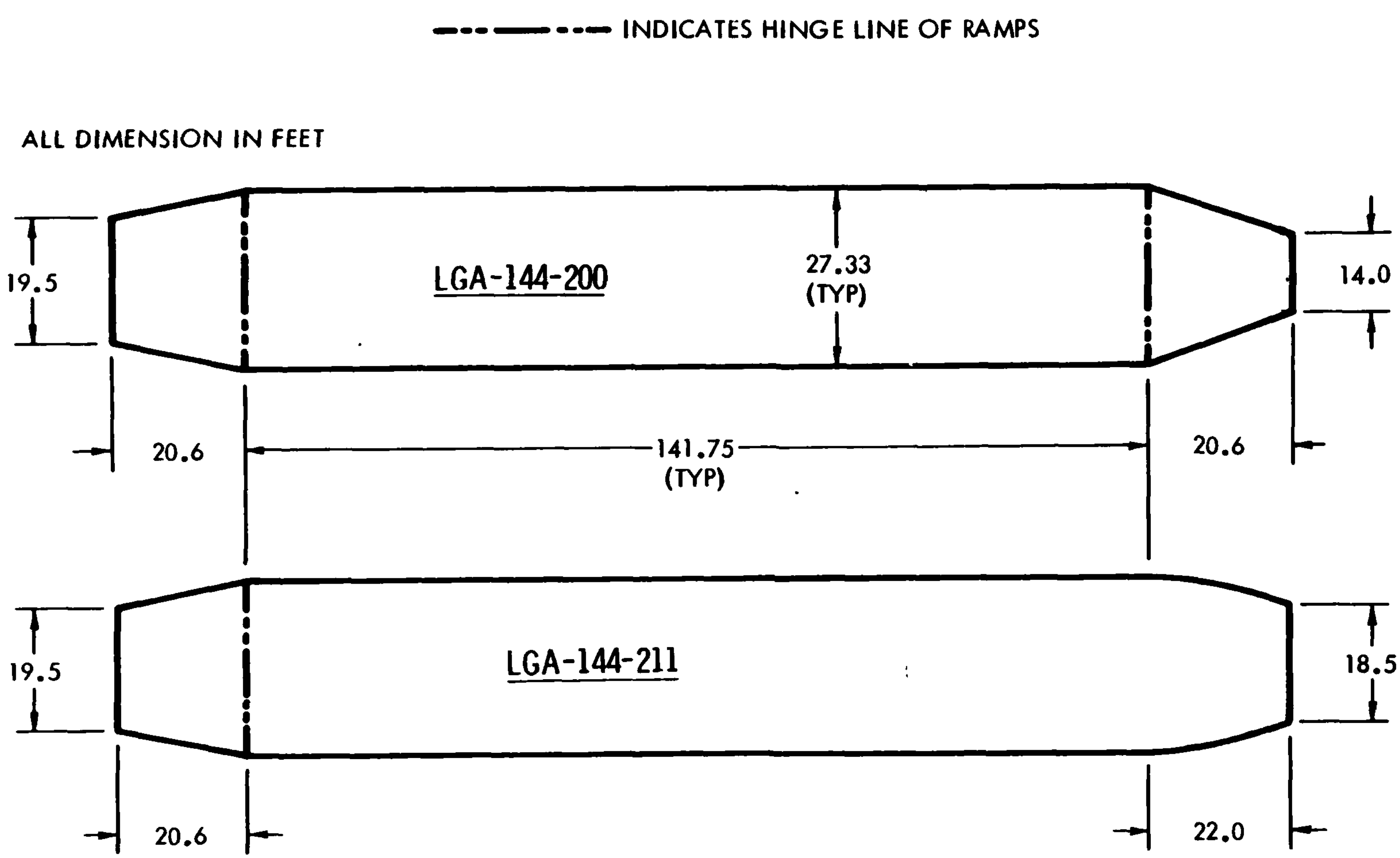


Figure 20. Cargo Compartment Planform Comparison: -200 and -211

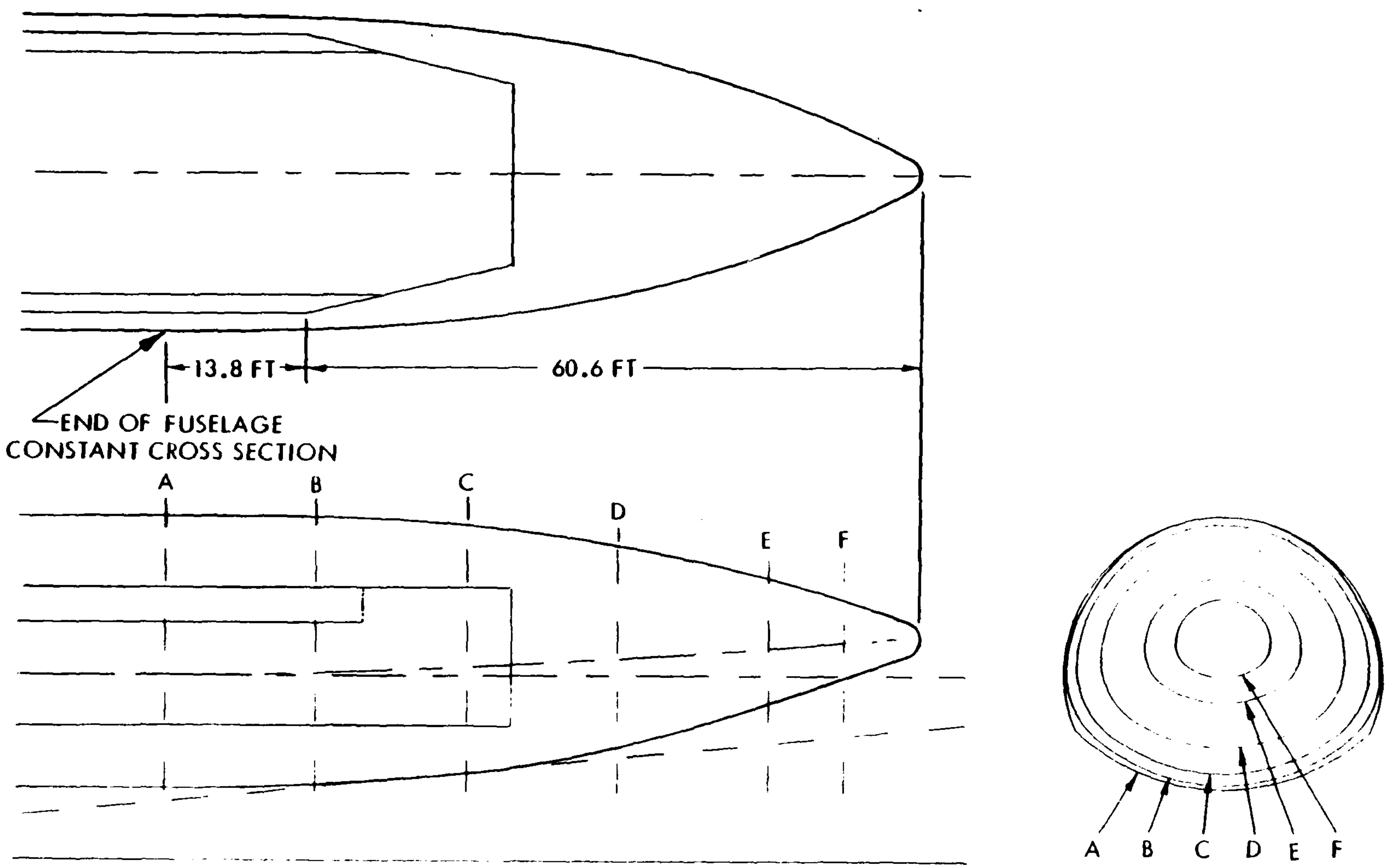


Figure 21. Aft Fuselage with Rear Aperture Deleted

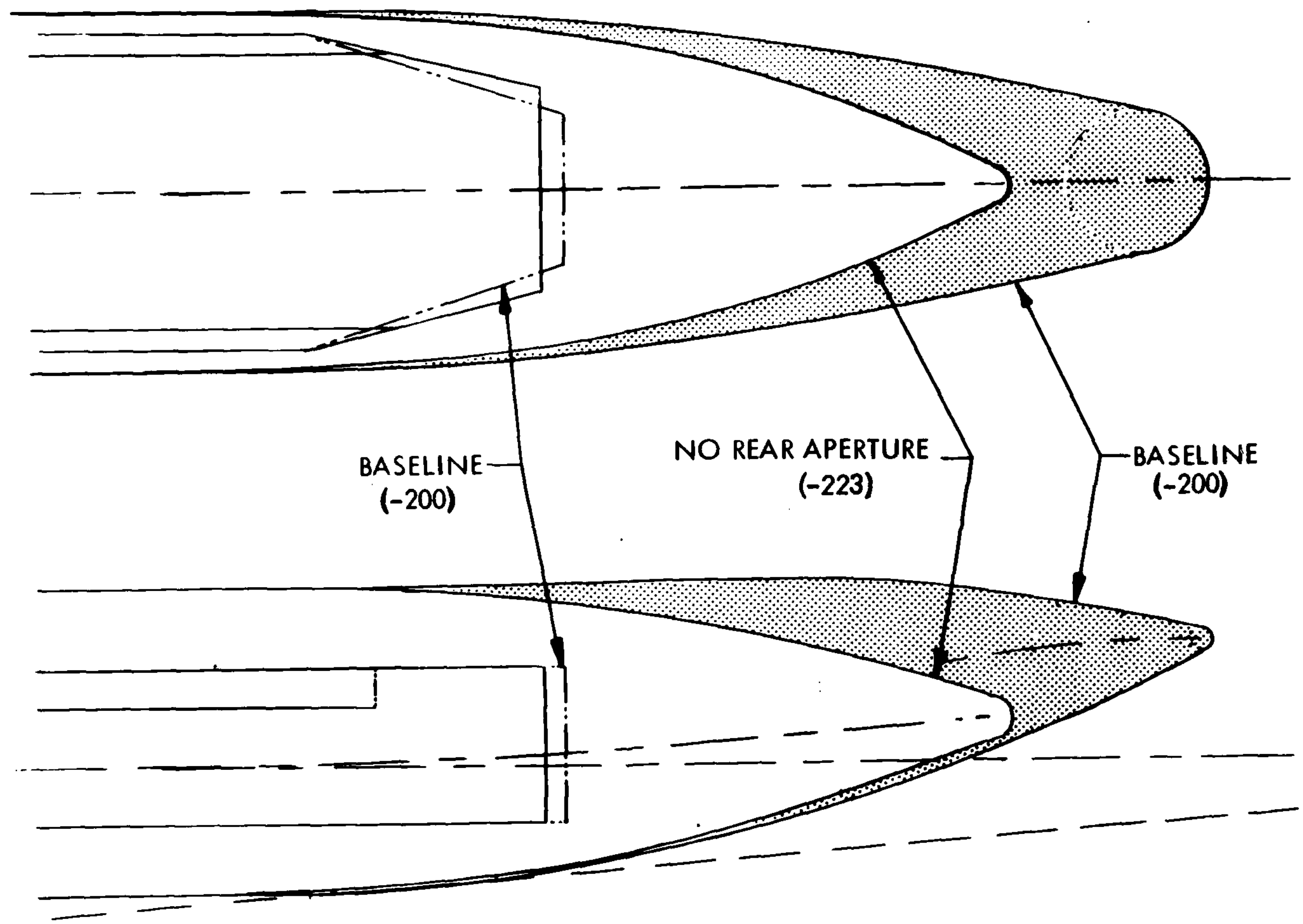


Figure 22. Comparison of Aft Fuselage Arrangements: -200 and -211/-223

The structural changes are also considerable. Deleted are the door hinges, latches and actuation system, ramp extensions, and pressure seals. Empennage loads can be taken out through a much larger and more efficient structural torque box since the door cut-out no longer exists.

The effects of deleting the aft aperture are discussed here by comparing the -200 with the -211. As shown in the upper half of Table 10, the effects of this option on the fuselage are on the order of a 6 percent reduction in fuselage length, wetted area, and pressurized volume, and almost a 19 percent reduction in form drag. The -211 aircraft was reoptimized with this smaller fuselage, and is described in detail in Appendix D. Some comparisons of figures of merit are given at the bottom of Table 10. Deleting the rear door results in more efficient use of the fuselage volume and in dramatic improvements in fuel consumed per unit payload.

Widening the Forward Aperture to Full-Width

The full-width forward aperture is incorporated on the -221, -222, and -223. The resulting cargo compartment planform is shown in Figure 23 for the -222. The additional width allows a third container to be positioned on the forward ramp, increasing the payload by 15,000 pounds for the three point-designs incorporating the option.

The principal difficulties encountered with the full-width opening are the decreased forebody fineness ratio, stowage of full-width ramp extensions, and the increased size and weight of the visor nose door. A description of the process leading to the point design is given in Appendix D; however, some highlights are reviewed here. The loading requirements cause the fuselage shape above the floor to remain constant all the way to the end of the ramp. The contour at the bottom of the fuselage is allowed to taper from the ramp hinge station forward, but as shown in Figure 24, the net effect is a reduced forebody fineness ratio. Storage of the retracted ramp extensions was first attempted by rotating them back over the ramp floor space. Effectiveness analyses, discussed in Appendix H, showed a large penalty for this storage scheme. Consequently, the ramp extensions are stowed vertically and are slightly tapered to stay within fuselage contour.

TABLE 10

EFFECT OF ELIMINATING THE AFT APERTURE

PARAMETER	-200	-211	% CHANGE
• FUSELAGE CHANGE			
- LENGTH - FT	258.92	241.50	-6.7
- WETTED AREA - FT^2	21,730	20,308	-6.5
- PRESSURIZED VOLUME - FT^2	148,167	139,674	-5.7
- FORM DRAG - COUNTS	53	43	-18.9
• FIGURES OF MERIT			
- PAYLOAD / GROSS WT	.356	.377	5.9
- AMPR WT / PAYLOAD	.903	.815	-9.7
- FUEL WT / PAYLOAD	.698	.643	-7.9

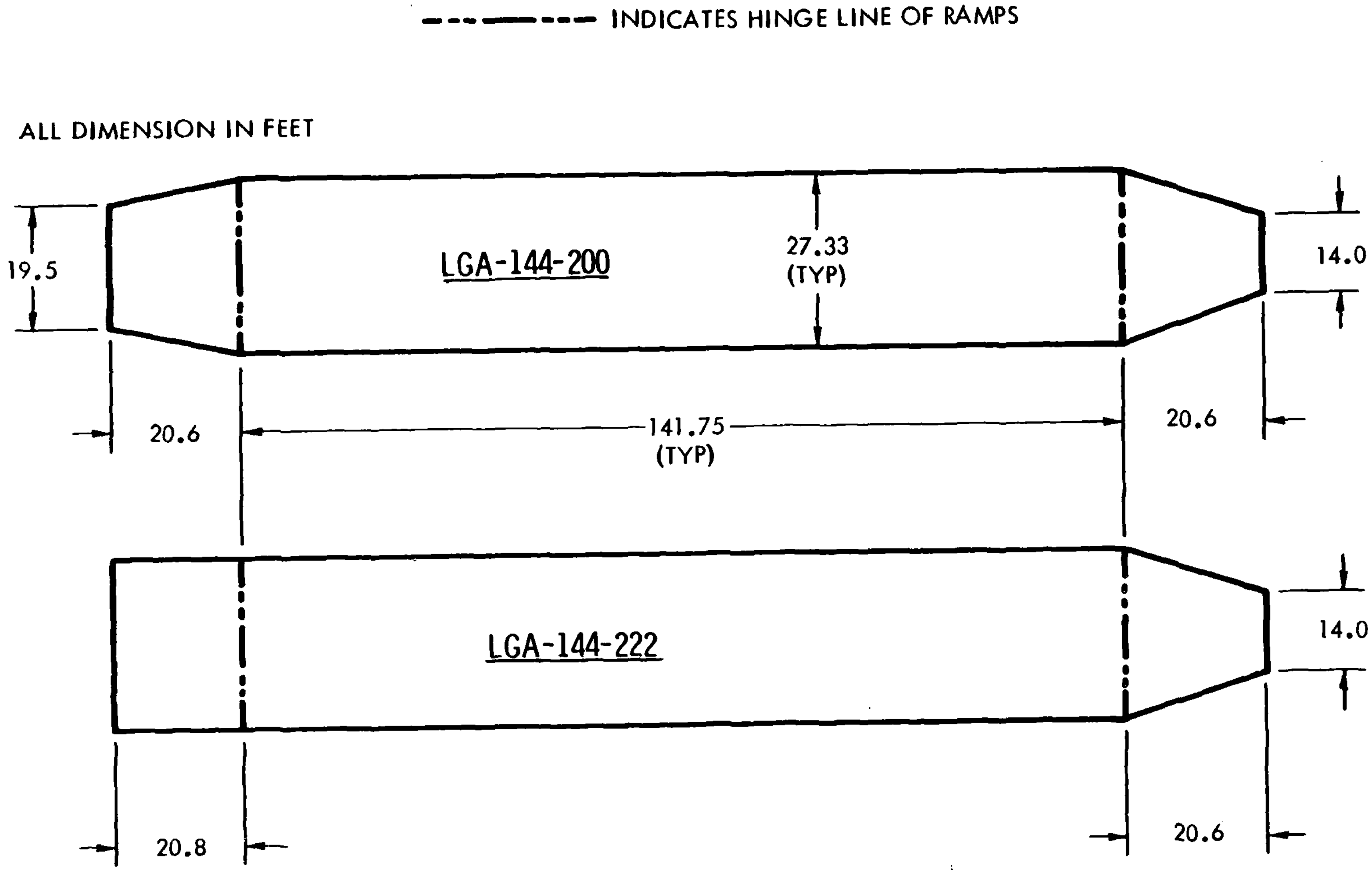


Figure 23. Cargo Compartment Planform Comparisons: -200 and -222

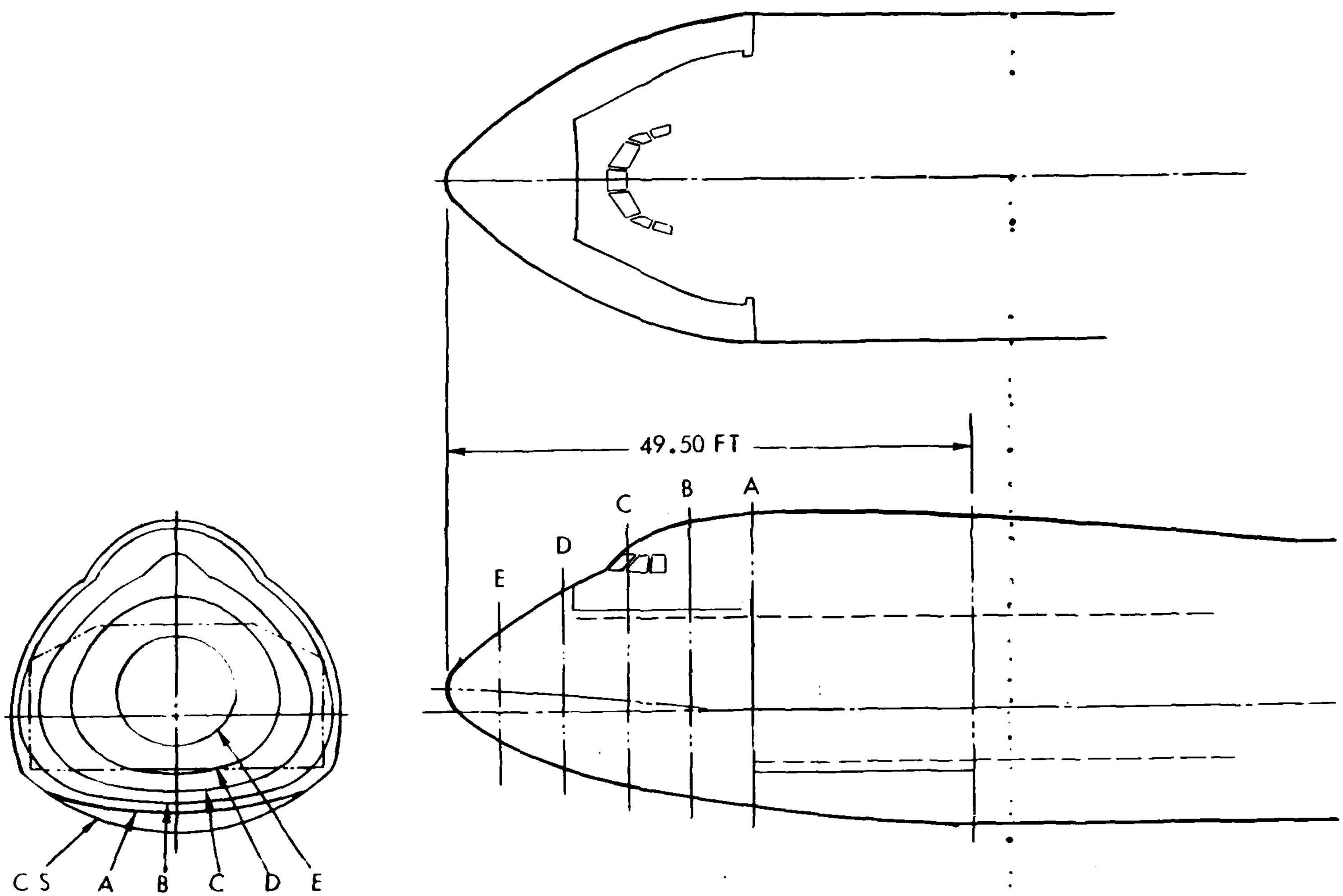


Figure 24. Forward Fuselage with Full-Width Aperture

A comparison of the external shapes of the -200 baseline forebody and the new forebody incorporating the full-width aperture is shown in Figure 25. The difference between the two (the shaded area), is approximately four percent for all the fuselage parameters shown in Table 11. After reoptimization, the penalties in payload fraction and fuel economy for the full-width forward door are one to two percent, as shown at the bottom of Table 11.

Widening the Rear Aperture to Full-Width

This option is incorporated on the -221 point design. The design problems encountered and their solutions are similar to the full-width forward aperture. The -221 cargo compartment planform is shown in Figure 26, where the two additional container positions can be seen on the rear ramp. The new external geometry is depicted in Figure 27, and is compared to the baseline aftbody in Figure 28.

The resulting fuselage measures are given at the top of Table 12. The full-width rear aperture option, incorporated on the -221, is compared to the -222, since both have full-width forward apertures, and only the change at the rear of the aircraft is therefore being examined. Interestingly, however, when the aircraft is reoptimized, the effect of the additional 30,000 pounds of payload compensates for the penalties of the full-width rear aperture. As can be seen at the bottom of Table 12, payload fraction actually improves slightly and both the AMPR weight per unit payload and the fuel consumed per unit payload are also improved.

The Interesting Combination

Given the improvements resulting from deletion of the rear door and the potential flexibility of a full-width forward door, an interesting combination of these previous options was incorporated into the -223. The cargo compartment planform of this point design is depicted on Figure 29. This arrangement picks up one additional container position on the forward ramp and one in the tapered floor area at the rear, increasing the payload to 390,000 pounds. The resulting fuselage parameters and physical figures of merit are shown in Table 13. The benefits of the new aft fuselage may then cancel out the penalties of

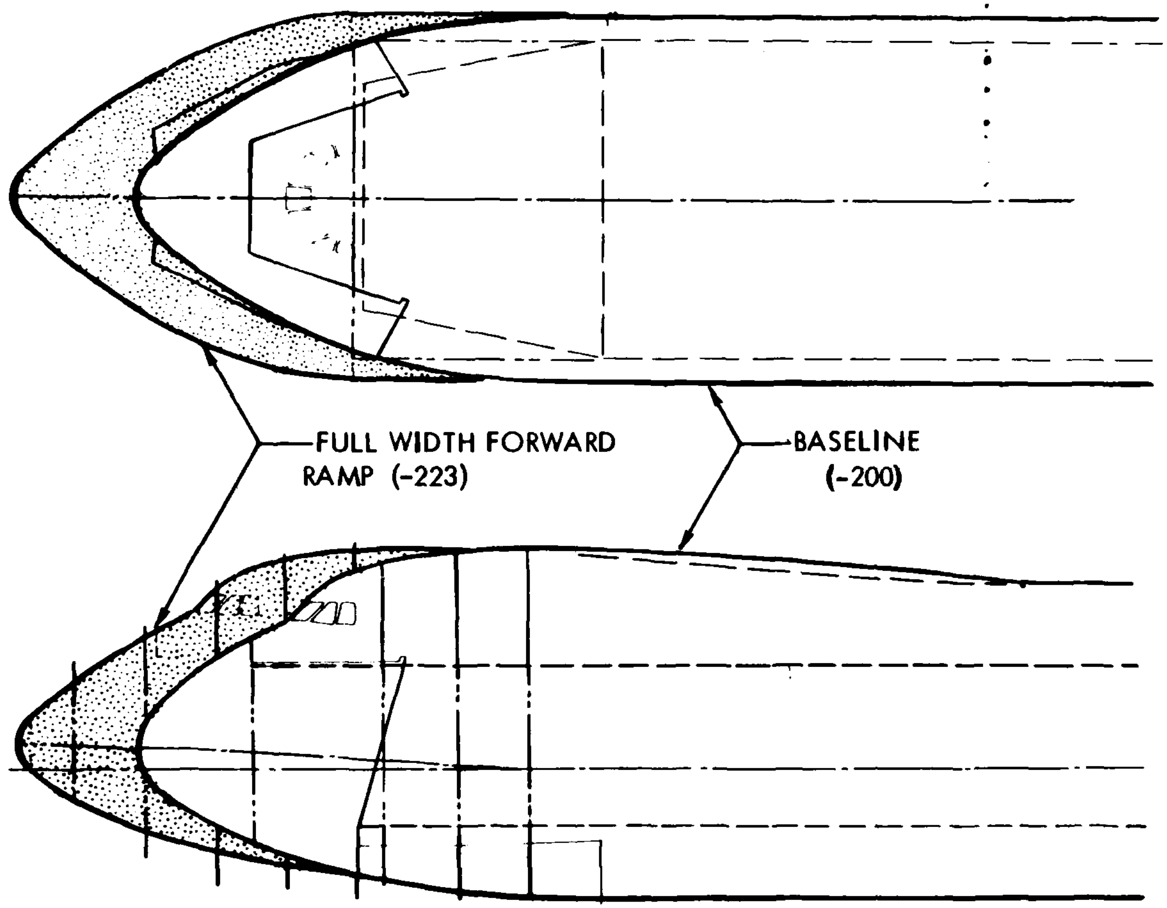


Figure 25. Comparison of Forward Fuselage Arrangements: -200 and -221/-223

TABLE 11

EFFECT OF INCORPORATING A FULL-WIDTH FORWARD APERTURE

PARAMETER	-200	-222	% CHANGE
• FUSELAGE CHANGE			
– LENGTH - FT	258.92	269.25	+3.9
– WETTED AREA - FT^2	21,730	22,697	+4.5
– PRESSURIZED VOLUME - FT^3	148,167	154,455	+4.2
– FORM DRAG - COUNTS	53	55	+3.8
• FIGURES OF MERIT			
– PAYLOAD / GROSS WT	.356	.353	-0.8
– AMPR WT / PAYLOAD	.903	.919	+1.8
– FUEL WT / PAYLOAD	.698	.703	+0.7

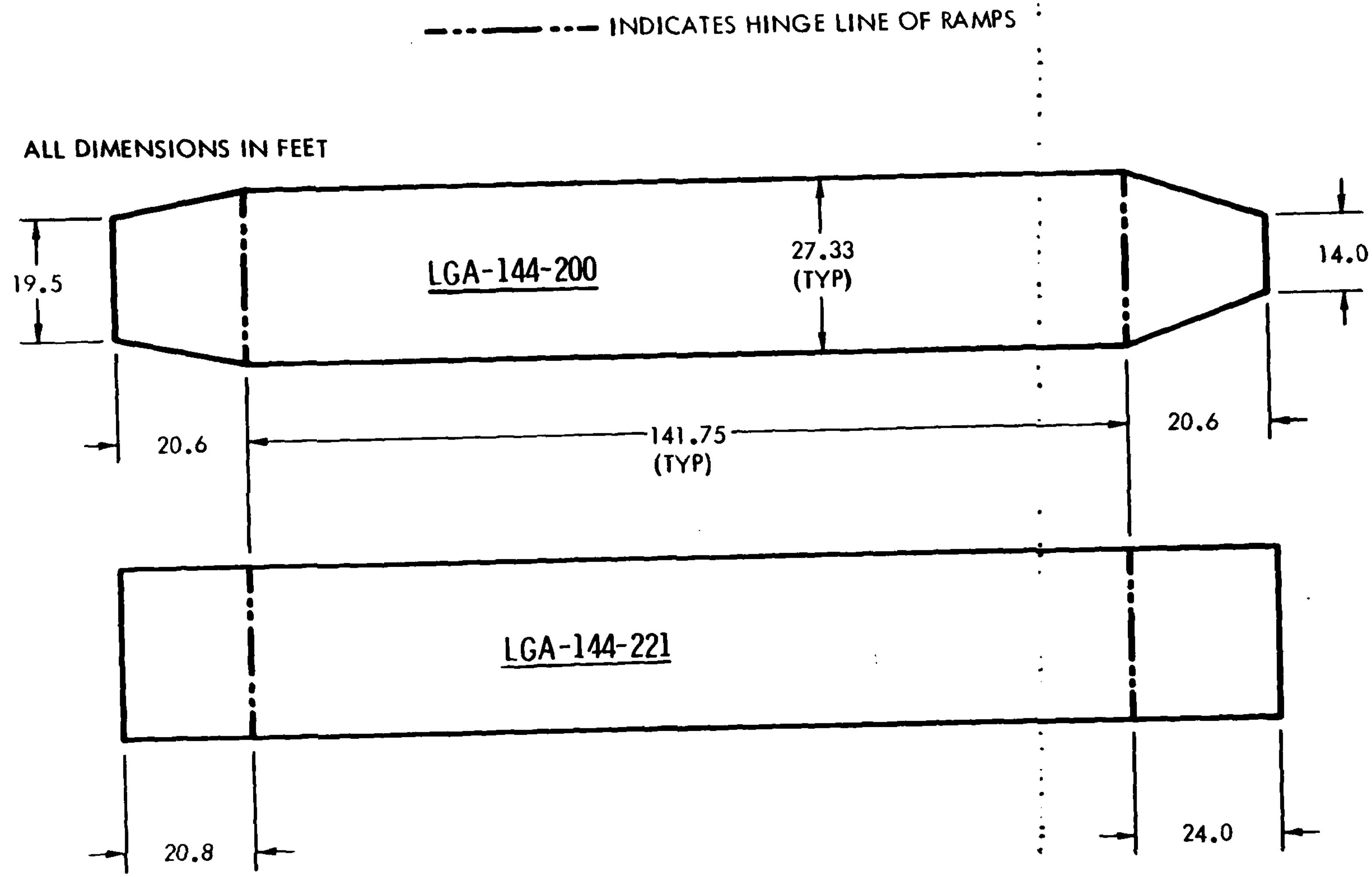


Figure 26. Cargo Compartment Planform Comparison: -200 and -221

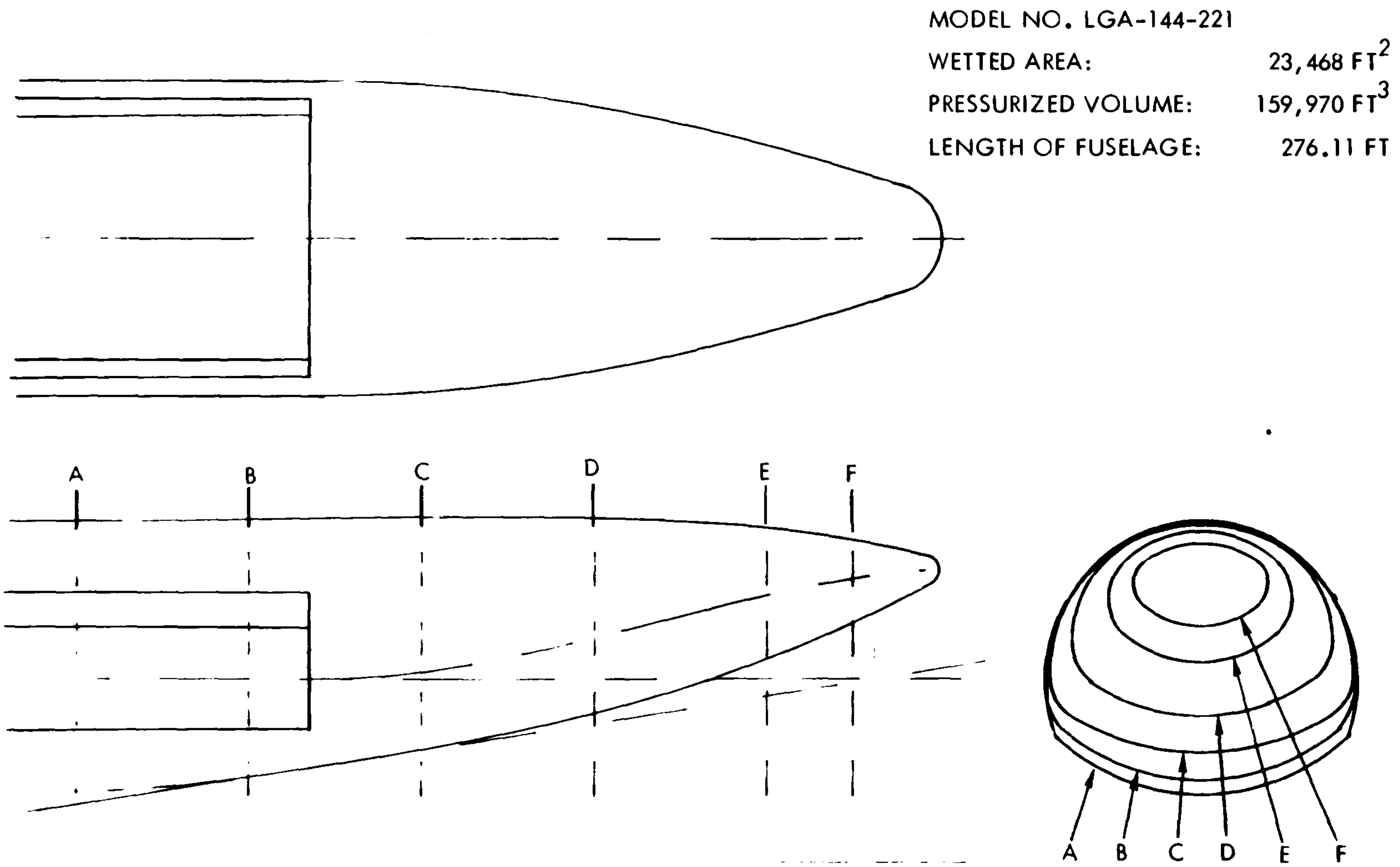


Figure 27. Aft Fuselage with Full-Width Aperture

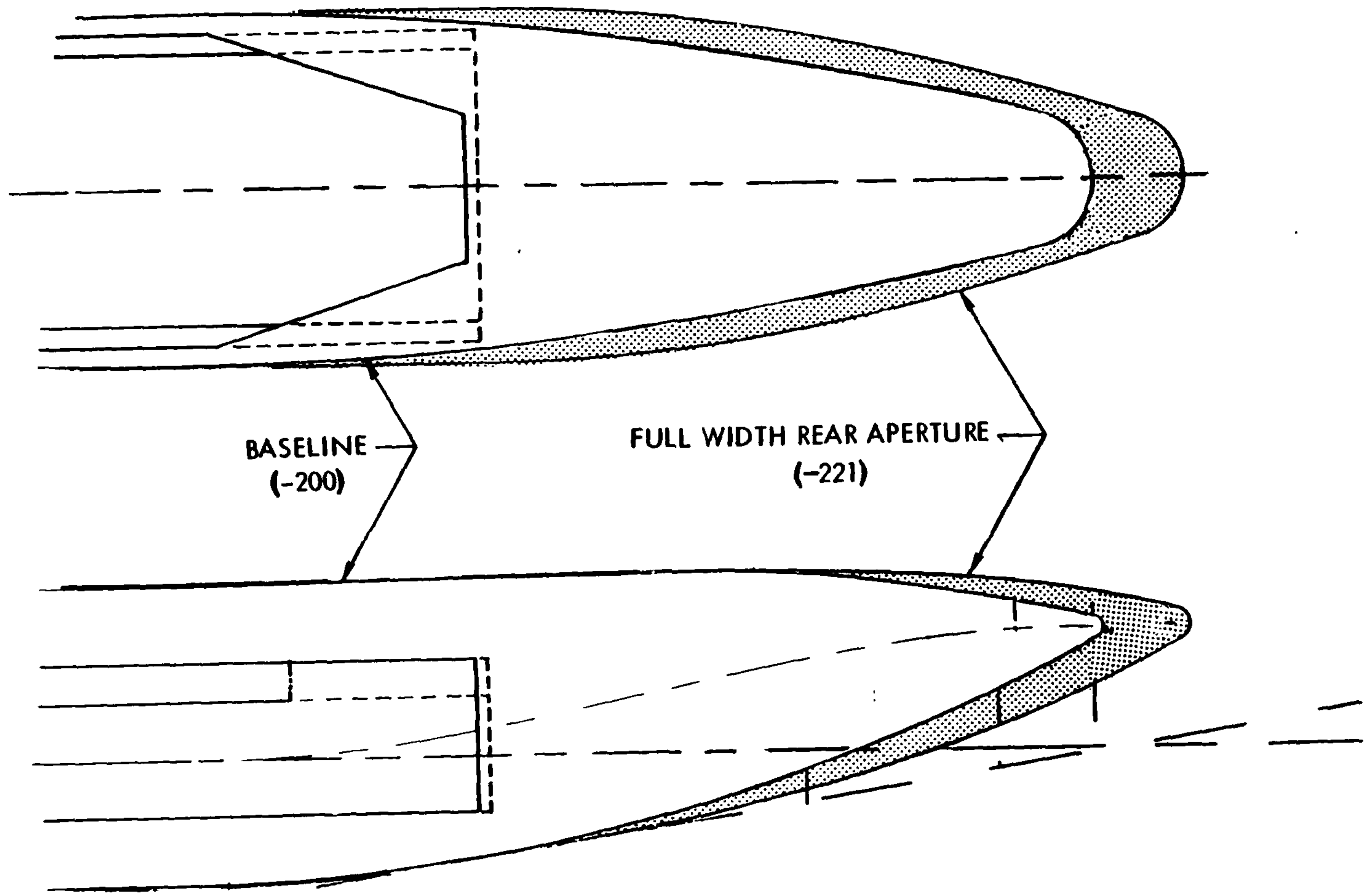


Figure 28. Comparison of Aft Fuselage Arrangements: -200 and -221

TABLE 12

EFFECT OF INCORPORATING A FULL-WIDTH FORWARD APERTURE

PARAMETER	-222	-221	% CHANGE
• FUSELAGE CHANGE			
- LENGTH - FT	269.25	276.11	+2.5
- WETTED AREA - FT^2	22,697	23,468	+3.4
- PRESSURIZED VOLUME - FT^3	154,455	159,970	+3.6
- FORM DRAG - COUNTS	55	60	+9.1
• FIGURES OF MERIT			
- PAYLOAD / GROSS WT	.353	.355	+0.6
- AMPR WT / PAYLOAD	.919	.910	-1.0
- FUEL WT / PAYLOAD	.703	.701	-1.7

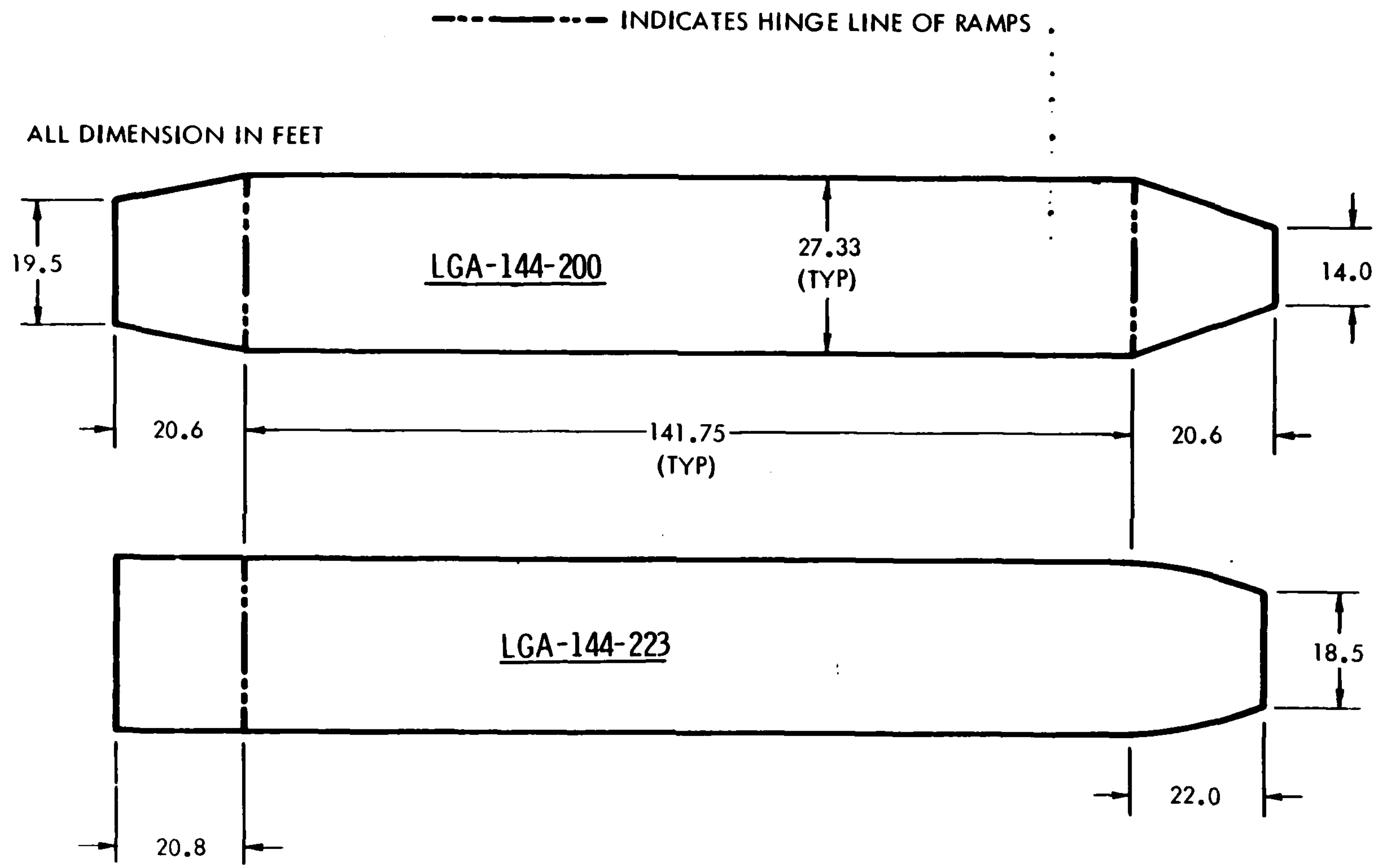


Figure 29. Cargo Compartment Planform Comparison: -200 and -223

TABLE 13

EFFECT OF FULL-WIDTH FORWARD BUT NO AFT APERTURE

PARAMETER	-200	-223	% CHANGE
• FUSELAGE CHANGE			
- LENGTH - FT	258.92	251.83	-2.7
- WETTED AREA - FT^2	21,730	21,275	-2.1
- PRESSURIZED VOLUME - FT^3	148,167	145,962	-1.5
- FORM DRAG - COUNTS	53	44	-17.0
• FIGURES OF MERIT			
- PAYLOAD / GROSS WT	.356	.374	+5.1
- AMPR WT / PAYLOAD	.903	.829	-8.2
- FUEL WT / PAYLOAD	.698	.647	-7.3

the revised forward fuselage, giving an aircraft with improved payload fraction and fuel efficiency.

Summary Comparisons

The -200 baseline aircraft and these four point-designs were subjected to detailed cost and effectiveness analyses that are covered in Appendix G and Appendix H, respectively. The summary comparisons presented in the next two tables are an attempt to compile, in one place, data that will be useful to ACMA decisionmakers.

The loading/unloading apertures design feature is summarized in Table 14. Numerical data are given for the -200 baseline, and percentage changes relative to these data are shown for the option to delete the rear door, for both 19.5-foot and 27.33-foot (full-width) forward doors.

Simply deleting the rear aperture offers major improvements in most of the figures of merit, in both military and commercial contexts. Military effectiveness is degraded about 3 percent because only one door is available to unload the aircraft and there is less floor space per unit payload, leading to lower average payloads. However, the savings in life-cycle costs is great enough to overwhelm this penalty. The commercial operator would, of course, be delighted with the 7 percent improvement in direct operating costs.

In combination with the full-width forward door, the option to delete the rear aperture faces weaker arguments in its favor. The military life-cycle costs are improved less, and effectiveness is further degraded because the design payload is increasing faster than the available floor space, in accordance with the assumptions on containers determining design payload; cost-effectiveness is now only 1 percent better than the baseline. The commercial operator faces a higher initial purchase price, but still reaps a 6 percent better DOC+ROI.

The cargo compartment planform design feature is summarized in Table 15. The baseline column contains real data and the other columns contain percent changes, the first for full-width apertures at the front and rear, and the

TABLE 14

LOADING/UNLOADING APERTURES SUMMARY COMPARISON

MODEL NUMBER	LGA-144-200	LGA-144-211	LGA-144-223
Fwd Aperture Width	19.5 Ft	19.5 Ft	27.3 Ft
Aft Aperture Width	13.0 Ft	None	None
TOTAL NUMBER OF AIRCRAFT	275	-4.0%	-7.6%
MILITARY			
Payload Fraction	0.356	+5.9%	+5.1%
Life-Cycle Costs ($ Bil)	32.1	-7.2%	-5.4%
NATO Effectiveness (Tons/Day)	23,300	-3.2%	-4.6%
Cost-Effectiveness ($ Mil/Tons/Day)	1.377	-4.2%	-0.9%
COMMERCIAL			
Fuel Economy (TNM/Gal)	20.8	+9.4%	+9.0%
Unit Price ($ Mil)	77.6	-3.0%	+3.1%
DOC (¢/ATNM)	6.12	-7.3%	-6.6%
DOC + ROI (¢/ATNM)	10.00	-7.0%	-5.8%

TABLE 15
CARGO COMPARTMENT PLANFORM SUMMARY COMPARISON

MODEL NUMBER	LGA-144-200	LGA-144-221	LGA-144-222
Fwd Aperture Width	19.5 Ft	27.3 Ft	27.3 Ft
Aft Aperture Width	13.0 Ft	27.3 Ft	13.0 Ft
TOTAL NUMBER OF AIRCRAFT	275	-11.3%	-4.0%
MILITARY			
Payload Fraction	0.356	-0.3%	-0.7%
Life-Cycle Costs ($ Bil)	32.1	+2.6%	+2.4%
NATO Effectiveness (Tons/Day)	23,300	-2.2%	-1.5%
Cost-Effectiveness ($ Mil/Tons/Day)	1.377	+4.9%	+4.0%
COMMERCIAL			
Fuel Economy (TNM/Gal)	20.8	-0.6%	-0.6%
Unit Price ($ Mil)	77.6	+17.0%	+6.7%
DOC (¢/ATNM)	6.12	+0.4%	+0.3%
DOC + ROI (¢/ATNM)	10.00	+1.9%	+1.2%

second for just the front. As might be expected, the full-width doors are expensive for both military and commercial operators. But perhaps not expected is the result that military effectiveness is degraded. This occurs because once again these aircraft suffer from the effects of increased payload per unit floor space that outweigh the decreased loading/unloading time. These results clearly demonstrate that careful effectiveness analysis is crucial to proper design option tradeoffs. Also of note is the observation that there are only small additional penalties for having a full-width rear door compared to the 13-foot wide rear door.

FLOOR HEIGHT

The floor height design feature analysis includes two options: the baseline landing gear capable of kneeling the aircraft to reduce the floor height from 13 to 8 feet, and a conventional gear leaving the floor 13 feet above the static ground line. The -200 baseline aircraft has the kneeling landing gear featured in Figures 30 and 31. The main landing gear consists of four bogies having six wheels each. The struts are located 17.7 feet from the aircraft centerline so the oleo strut does not interfere with the fuselage structure during kneeling. The retraction scheme consists of a 90-degree rotation of the bogie followed by retraction inward, with the bogie articulating to remain horizontal.

The option to eliminate the kneeling feature had the objective of developing a configuration that takes maximum advantage of the simpler gear and retraction scheme and a smaller landing gear pod. This was accomplished while maintaining the same LCG, tip-over angles, and cargo-loading-ramp angle.

The resulting gear arrangement is shown in Figures 32 and 33. The gear now retracts directly forward, articulating to remain horizontal. The gear pod is slightly smaller since the post is located under the floor of the cargo compartment. An adverse result of not having the kneeling capability is shown in Figure 34. With the same 11° ramp angle as the baseline, the ramp extensions are about twice as long. Storing these ramp extensions within the original fuselage contour required that they be retracted to an angle leaning aft, thus preventing some of the floor space from being utilized. A

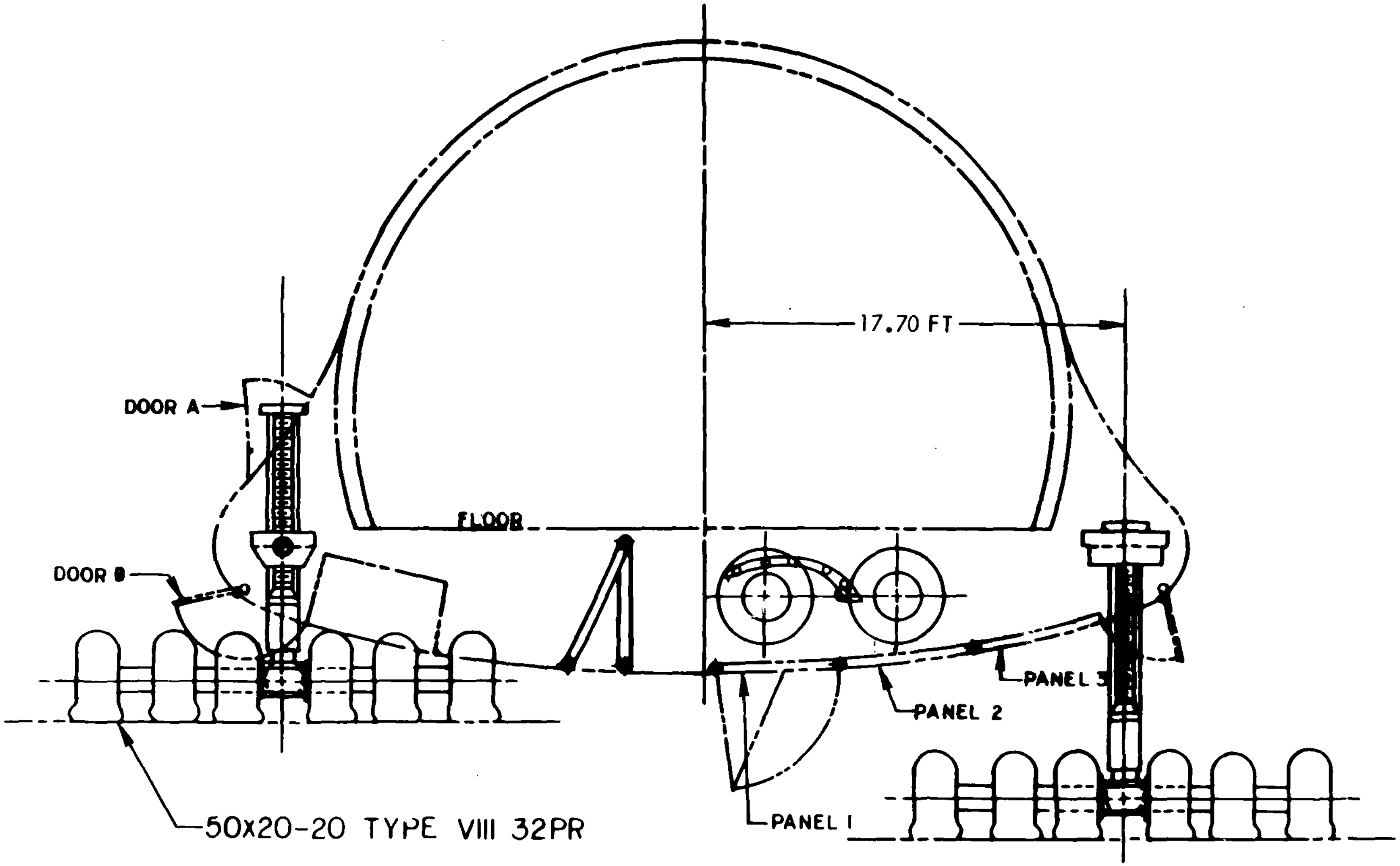


Figure 30. Baseline Landing Gear

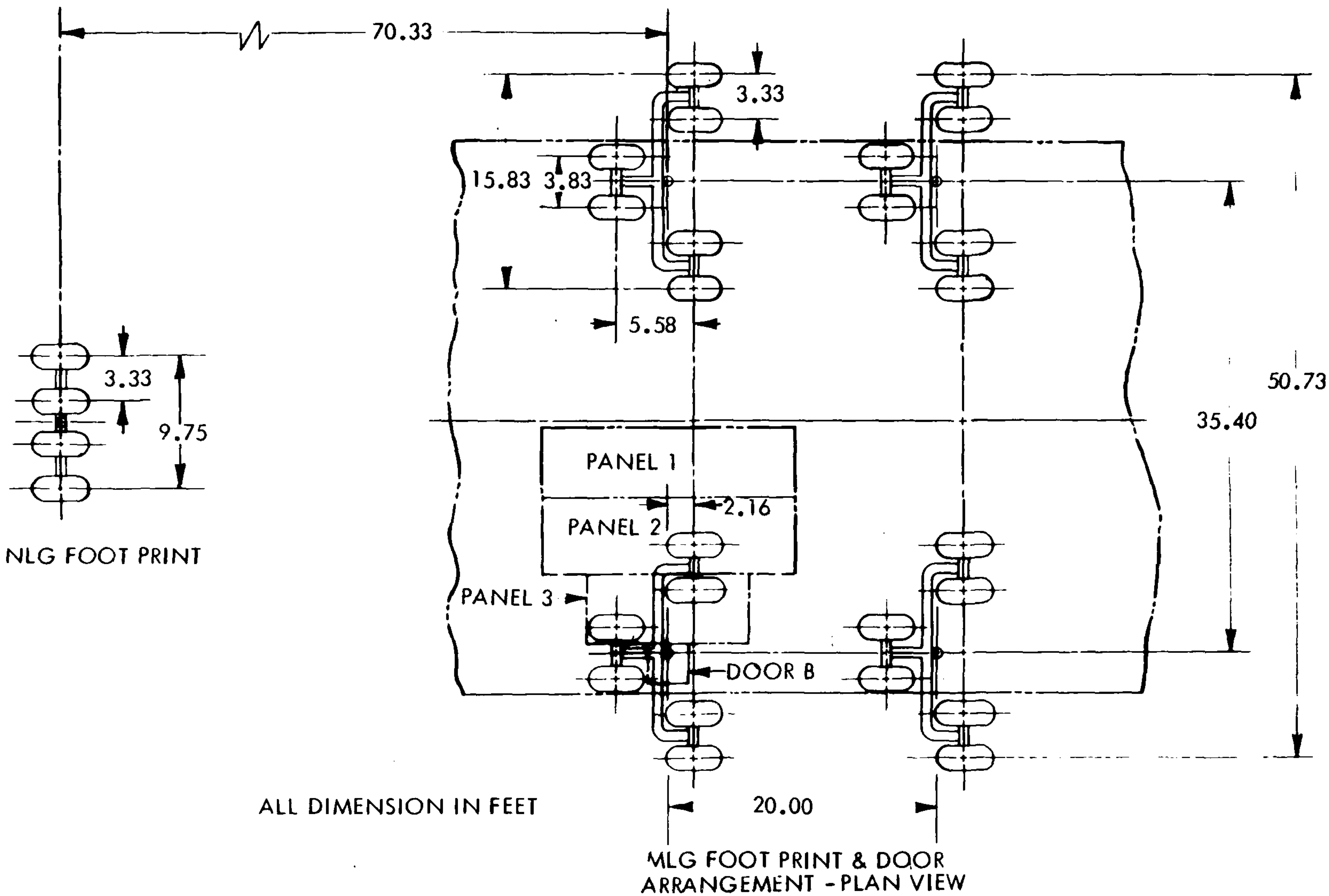


Figure 31. Baseline Landing Gear Footprint

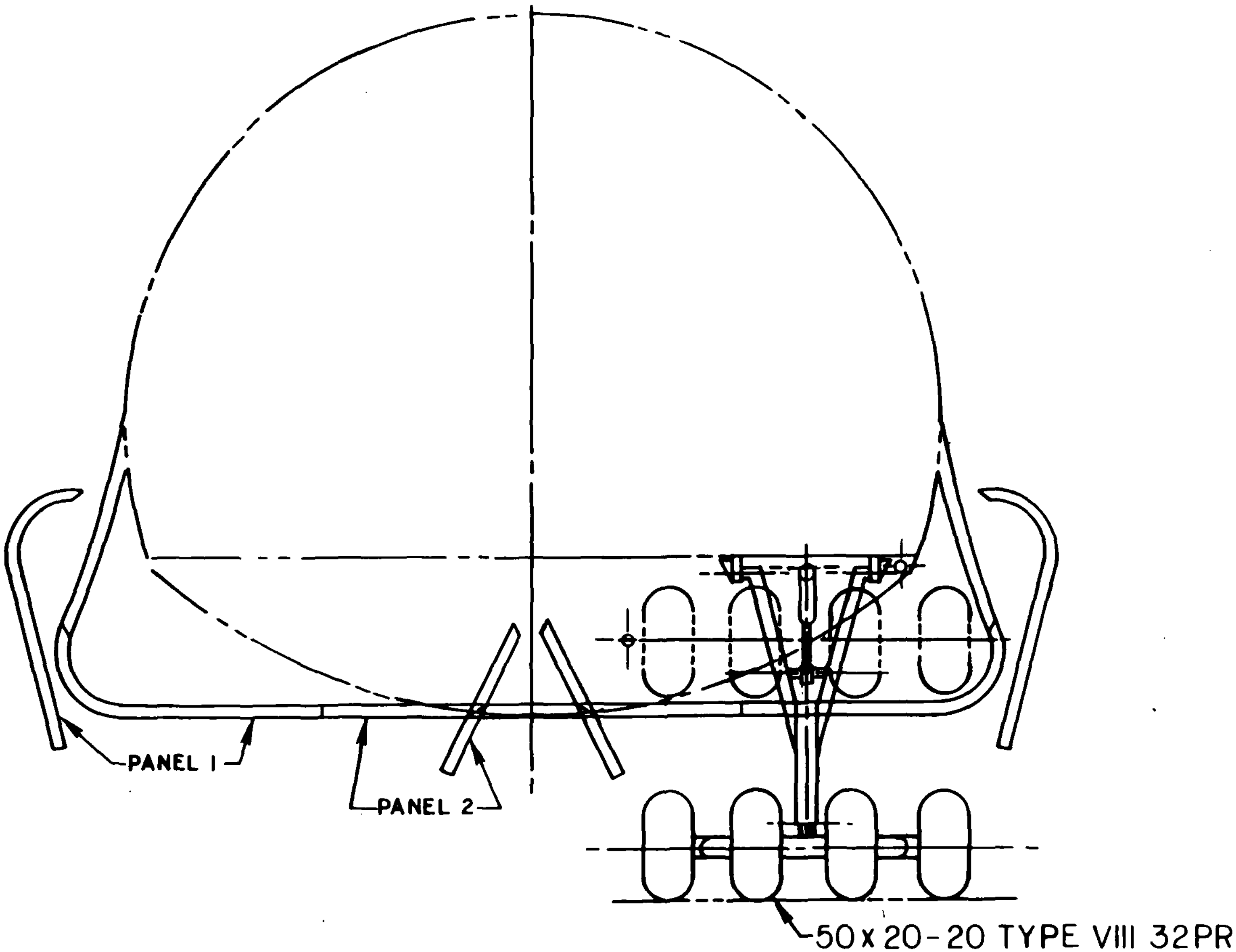


Figure 32. Non-Kneeling Landing Gear

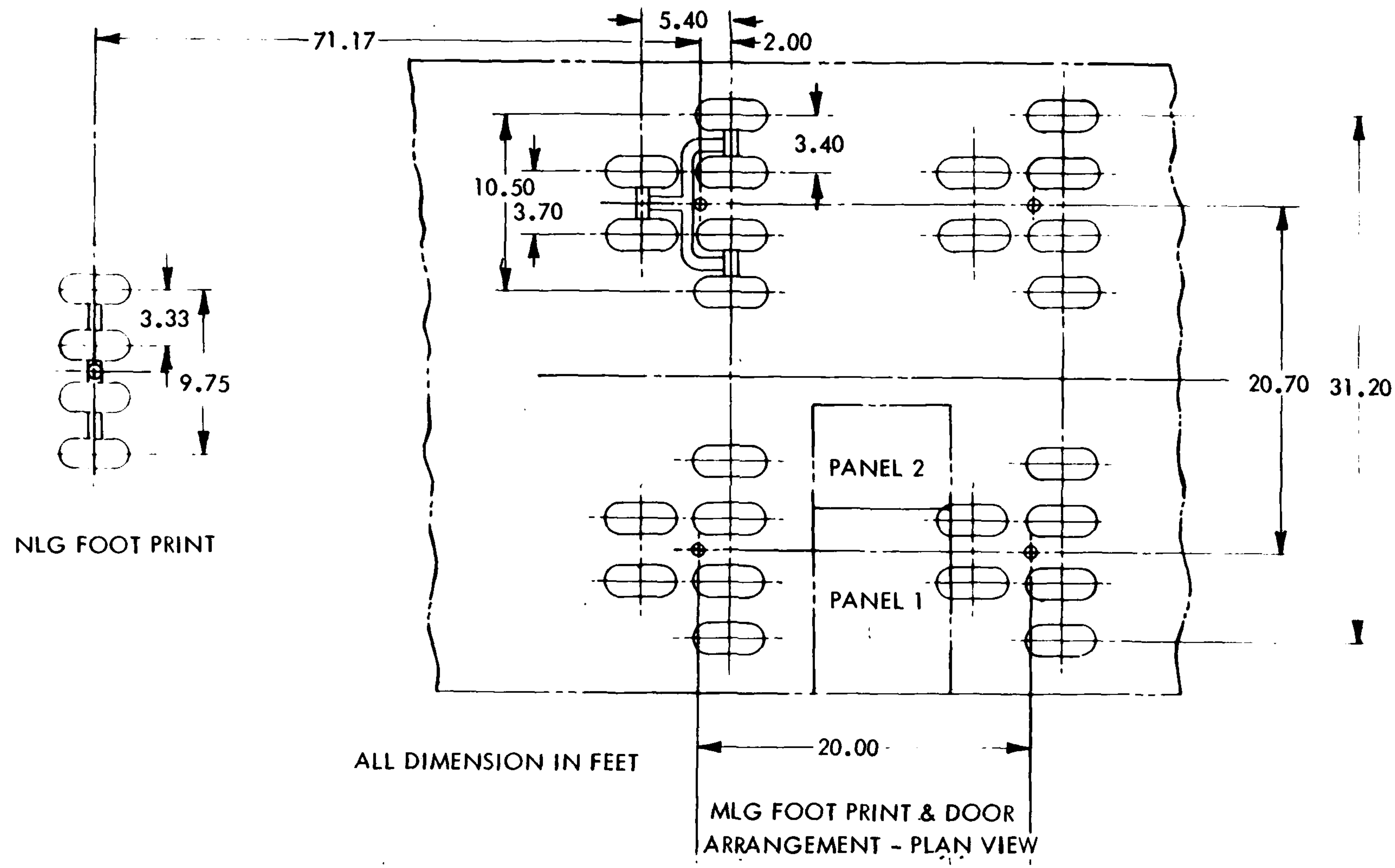


Figure 33. Non-Kneeling Landing Gear Footprint

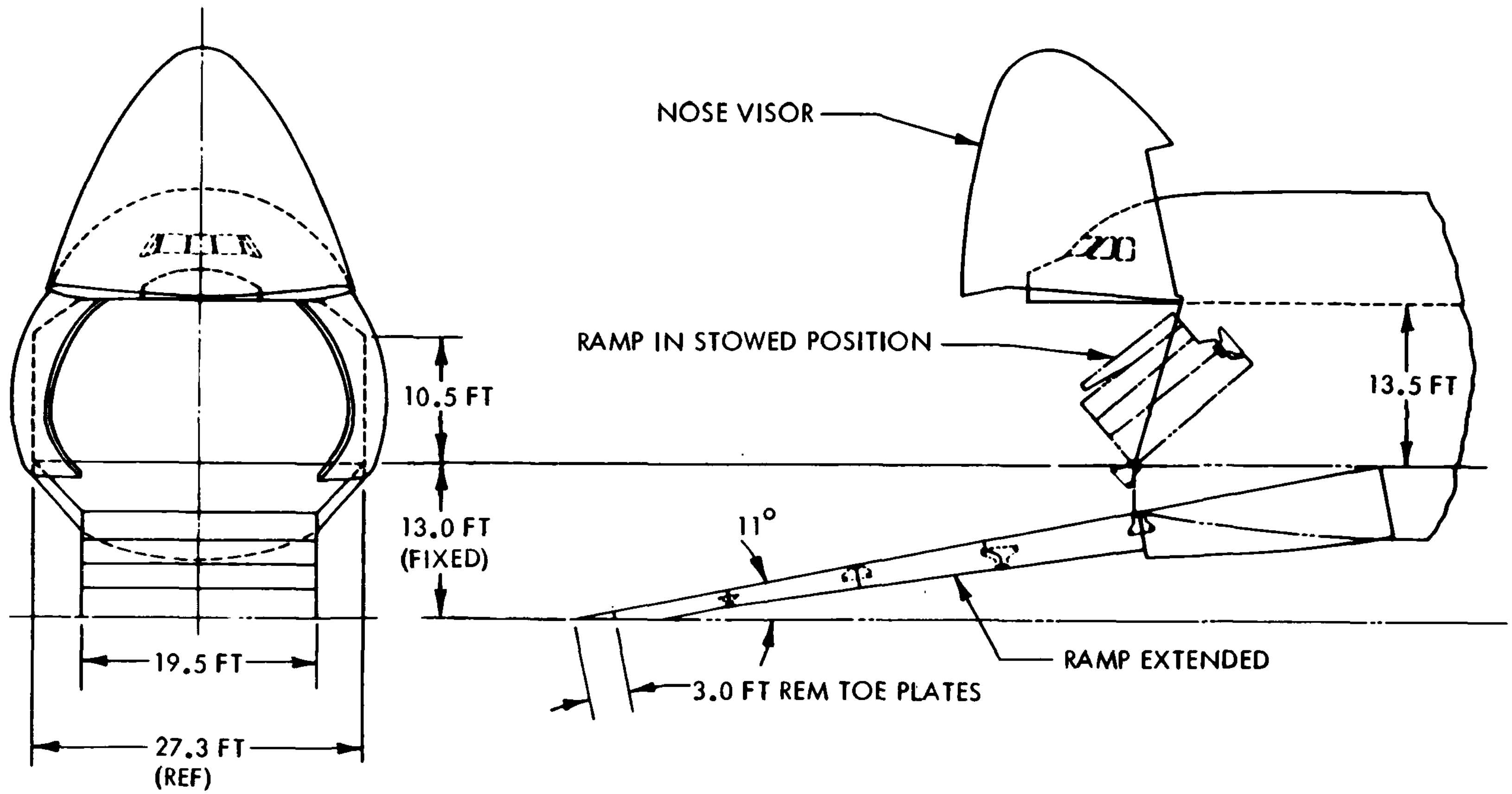


Figure 34. Ramp Extensions for the Non-Kneeling Aircraft

comparison of the -231 and the -200 cargo compartment planforms is shown in Figure 35.

The -231 aircraft, when reoptimized to the design mission, has the physical characteristics that are listed and compared to the -200 in Table 16. The net effect on the design of the total aircraft is small, about a 0.6 percent higher gross weight. Substantial effects are found, however, in the cost and effectiveness analyses. Table 17 is the summary comparison for the cargo compartment floor height design feature. Relative to the -200 baseline, the -231 has higher military life-cycle costs, poorer military effectiveness and, consequently, much poorer cost-effectiveness.

However, the picture is exactly the opposite for the commercial operator. His aircraft do not carry the ramp extensions, and thus has the full floor space available to carry his payloads. Therefore, he sees an advantage to the deletion of the kneeling gear of about 2-1/2 percent in direct operating costs.

SUMMARY OBSERVATIONS

The Group II analyses contain some interesting results. With regard to the rear aperture, it is clear from the commercial viewpoint that the rear door should be deleted. However, the military attractiveness of the rear aperture will depend on whether airdrop is required or if there will be variant missions requiring an aft aperture in the ACMA.

The width of the forward aperture is a cloudy area. When combined with a baseline-width rear door, a full-width forward door is a drawback relative to the baseline in both military and commercial contexts. But, when the rear door is deleted, the full-width forward door is marginally better in the military context and substantially better in the commercial context than the baseline. The fact not included in this analysis is that a full-width forward aperture ensures superior loading characteristics because any item that can be fitted in the cargo compartment can be loaded into the aircraft. Whether this is worth the modest penalty in commercial economics (relative to the -211) is uncertain at present.

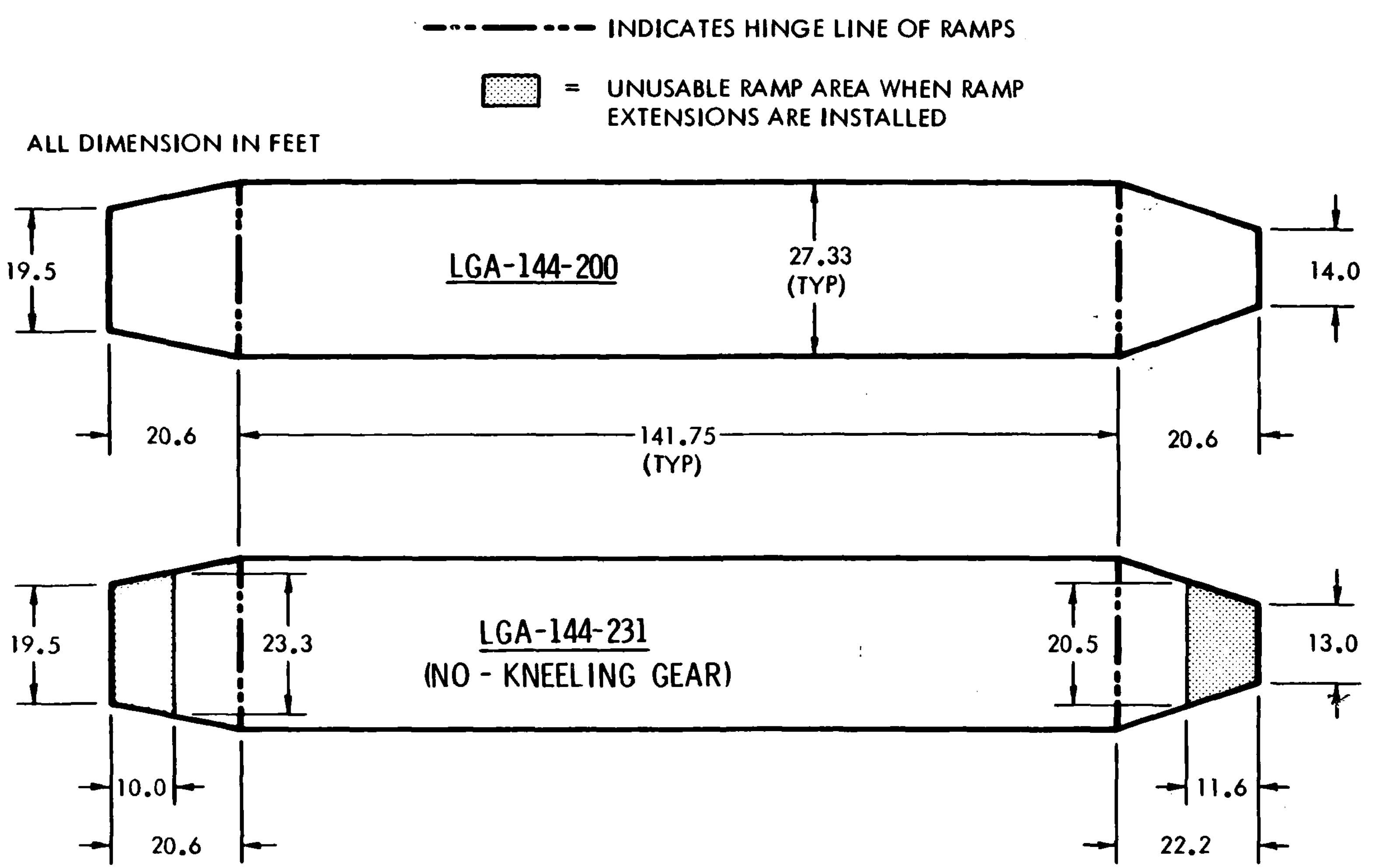


Figure 35. Cargo Compartment Planform Comparison: -200 and -231

TABLE 16

EFFECT OF ELIMINATING KNEELING FEATURE

PARAMETER	-200	-231	% CHANGE
• FLOOR AREA (USABLE, FT^2)	4,802	4,394	-8.5
• FLOOR HEIGHT (FT)			
NORMAL	13	13	—
KNEELED	8	—	—
• FUSELAGE WETTED AREA (FT^2)	21,730	21,666	-0.29
• RAMP EXTENSION WEIGHT (LB)	4,800	11,220	+134
FIGURE OF MERIT			
• GROSS WEIGHT (LB)	1,010,899	1,016,813	+0.59
• AMPR WEIGHT (LB)	325,094	330,935	+3.62
• FUEL WEIGHT (LB)	226,565	227,772	+0.53

TABLE 17
CARGO COMPARTMENT FLOOR HEIGHT SUMMARY COMPARISON

MODEL NUMBER	LGA-144-200	LGA-144-231	LGA-144-231
Floor Height	8 Ft	13 Ft	13 Ft
TOTAL NUMBER OF AIRCRAFT	275	275	-
MILITARY			
Payload Fraction	0.356	0.354	-0.6%
Life-Cycle Costs ($ Bil)	32.1	32.6	+1.7%
NATO Effectiveness (Tons/Day)	23,300	22,300	-4.1%
Cost-Effectiveness ($ Mil/Tons/Day)	1.377	1.460	+6.1%
COMMERCIAL			
Fuel Economy (TNM/Gal)	20.8	21.0	+1.3%
Unit Price ($ Mil)	77.6	77.0	-0.7%
DOC (¢/ATNM)	6.12	6.00	-2.4%
DOC + ROI (¢/ATNM)	10.00	9.74	-2.6%

The kneeling landing gear entails a small penalty for the commercial operator. However, deleting the kneeling gear results in a substantial penalty in military effectiveness, assuming the 11° ramp angle stays constant. This is the first example of a design feature representing a clear difference in the way military and commercial operators might prefer the ACMA configuration and suggests perhaps a commonality compromise. Another alternative is to provide compensation to the commercial operator so that he is indifferent, in terms of purchase price, DOC, and DOC+ROI, to whether his aircraft have kneeling landing gear. This is shown in Table 18 which should be compared to Table 17. The numbers in the -200 column have been changed for the commercial operator to reflect his indifference between the -200 and the -231. The cost of this compensation program, about $1.1 billion, is added to the military life cycle costs. Note, however, that the resulting cost effectiveness is still degraded (2.5 percent) by deleting the kneeling landing gear (i.e., kneeling is important enough to the military to warrant considering compensation).

At this point in the study, a Group II configuration was required for the Group IV analyses. The -223 was selected and approved by the Air Force Study Manager on 28 March 1979.

TABLE 18
KNEELING LANDING GEAR COMPENSATION COMPARISON

MODEL NUMBER	LGA-144-200	LGA-144-231	LGA-144-231
Floor Height	8 Ft	13 Ft	13 Ft
TOTAL NUMBER OF AIRCRAFT	275	275	-
MILITARY (Including Subsidy)			
Payload Fraction	0.356	0.354	-0.6%
Life-Cycle Costs ($ Bil)	33.2	32.6	-1.6%
NATO Effectiveness (Tons/Day)	23,300	22,300	-4.1%
Cost-Effectiveness ($ Mil/Tons/Day)	1.425	1.460	+2.5%
COMMERCIAL (With Subsidy)			
Fuel Economy (TNM/Gal)	20.8	21.0	+1.3%
Unit Price ($ Mil)	77.0	77.0	-
DOC (¢/ATNM)	6.00	6.00	-
DOC + ROI (¢/ATNM)	9.74	9.74	-

VI. GROUP III SUMMARY RESULTS

The Group III analyses deal with three important issues affecting the aircraft/airport interface: takeoff distance, landing gear flotation, and noise characteristics. Takeoff distance and gear flotation are combined into a single design feature for the present analysis. The FAA-required second-segment climb gradient is combined with FAR 36 noise requirements, since they are both necessary for ACMA civil certification.

The baseline for the Group III analysis is the -323. This aircraft, shown in Figure 36 is essentially the -200 configuration but reoptimized using a considerably more detailed takeoff distance computer code. The -200 takeoff distance characteristics are shown in Figure 37, depicting the changes from the original, overly conservative program. The new code correctly sized the -323 baseline for the 9500-foot takeoff distance over a 50-foot obstacle, as depicted in Figure 38.

TAKEOFF DISTANCE/LANDING GEAR FLOTATION

The Group III options for the takeoff distance/gear flotation design feature are composed of three field lengths (8000, 9500, and 10,500 feet), and two load classification groups (LCG II and LCG III). The combination of the 8000-foot field length and LCG II landing gear is not examined because few airports with that firm a runway surface are as short as 8000 feet.

8000-Foot Takeoff Distance/LCG III

The first option attempts to determine the penalties of requiring an improvement in takeoff performance relative to the baseline, while maintaining the same landing gear flotation. The aircraft incorporating this option, the -313, has the takeoff characteristics presented in Figure 39. The three ways of describing takeoff distance are used to illustrate takeoff performance in Table 19, along with other -313 figures of merit and a comparison with the -323 baseline. Note that critical field length and FAA field length are reduced by about the same percentage as the takeoff distance over 50 feet.

9500 FT FIELD LENGTH

CRUISE MACH NO.	0.78
DESIGN PAYLOAD	360,000 LB
DESIGN RANGE	4,000 NM
OPERATING WT	394,000 LB
MAX. GROSS WT	1,005,000 LB
ASPECT RATIO	10.28
WING LOADING	129.4 PSF
THRUST PER ENGINE	56,100 LB

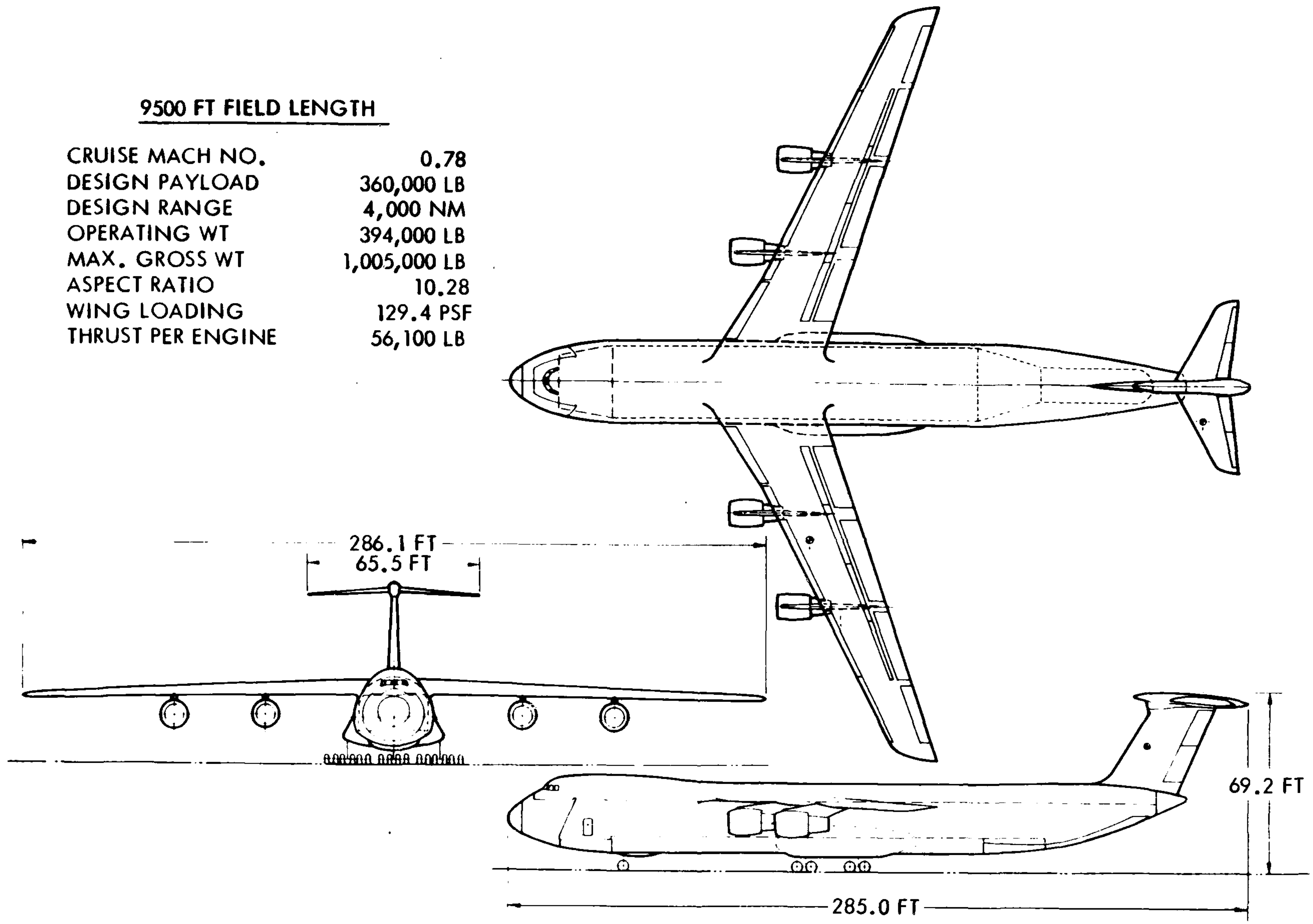


Figure 36. General Arrangement: LGA-144-323

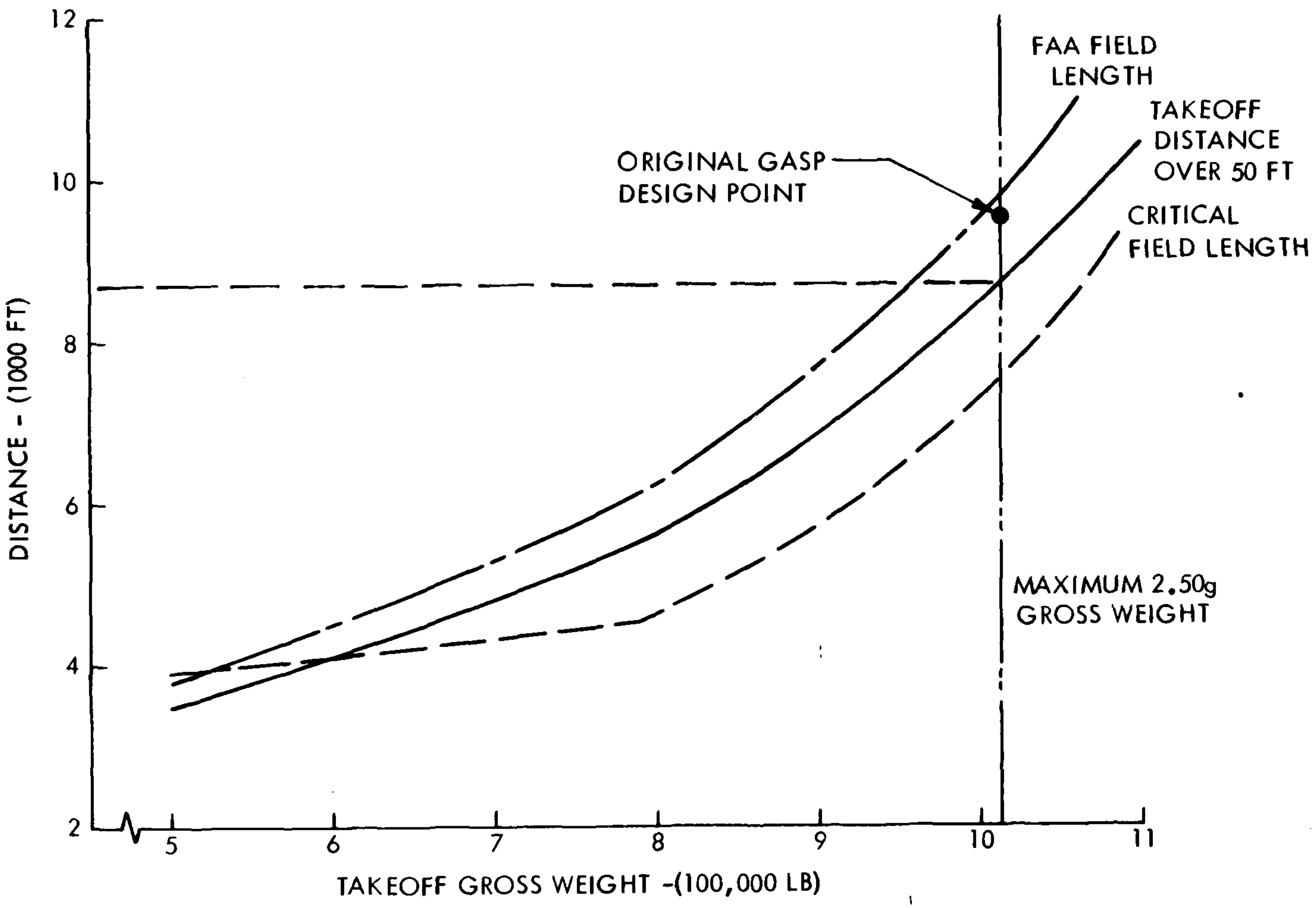


Figure 37. Takeoff Distance Characteristics: LGA-144-200

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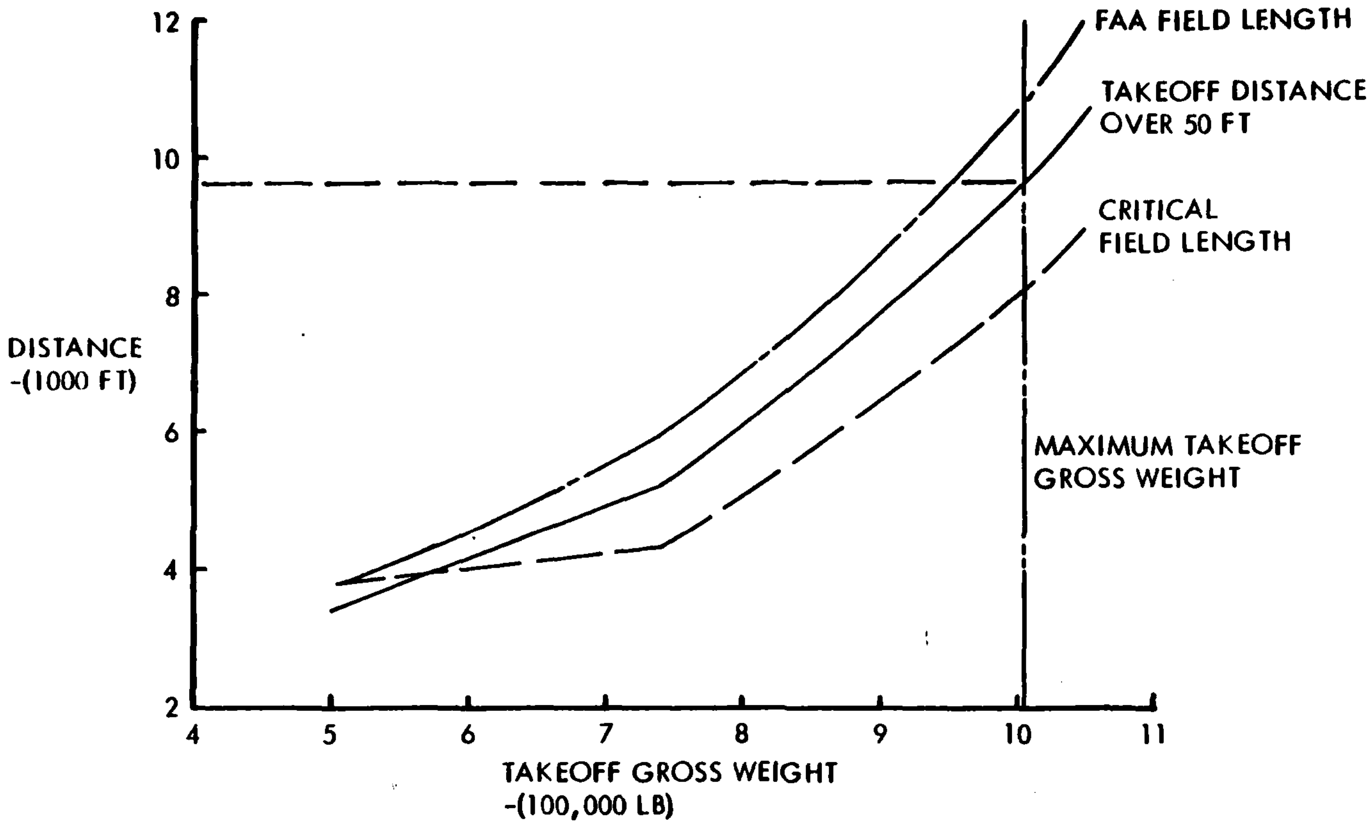


Figure 38. Takeoff Distance Characteristics: LGA-144-323

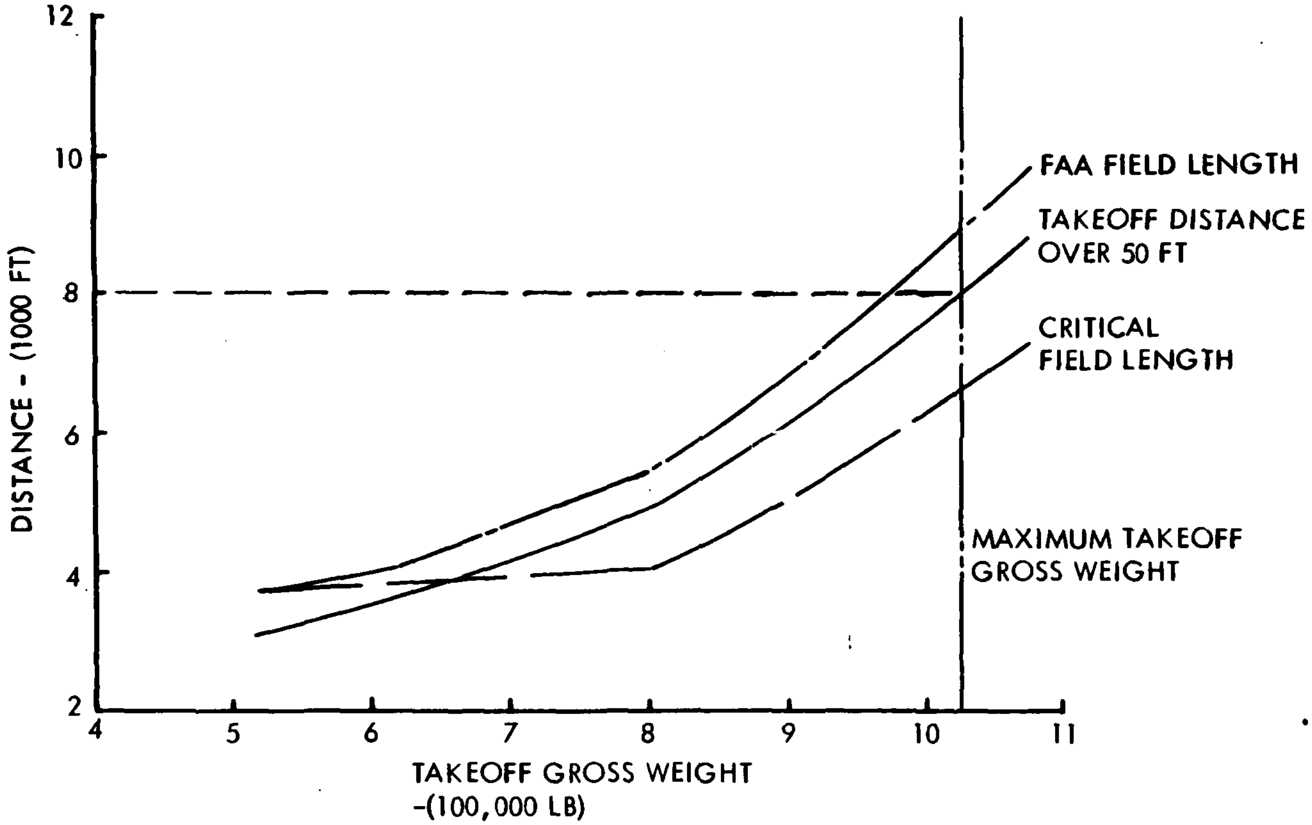


Figure 39. Takeoff Distance Characteristics: LGA-144-313

TABLE 19

EFFECT OF 8000-FT TAKEOFF DISTANCE

PARAMETER	-323	-313	% CHANGE
● TAKEOFF DISTANCES (MGTOW) (FT)			
- OVER 50 FT	9,500	8,000	-15.8
- CRITICAL FIELD LENGTH	7,950	6,630	-16.6
- FAA FIELD LENGTH	10,630	8,920	-16.1
● FIGURES OF MERIT			
- GROSS WEIGHT	1,004,700	1,025,200	2.0
- ENGINE THRUST	56,090	64,930	15.8
- T/W	.2223	.2533	113.9
- AMPR WEIGHT	321,770	324,870	1.0
- FUEL WEIGHT	250,510	260,840	4.1

The 8000-foot requirement causes about a 2 percent higher gross weight, 16 percent higher-thrust engines, and a 4 percent greater fuel load.

10,500-Foot Takeoff Distance/LCG III

This option analyzes the potential benefits of relaxing the field length requirement to 10,500 feet, maintaining the same LCG as the baseline. Figure 40 depicts the takeoff characteristics of the -333, which incorporates this option. Table 20 shows that, again, critical field length and FAA field length track along with the takeoff distance over 50 feet in terms of percentage increase. The benefits in lower gross weight, however, are only about 0.8 percent, and engine thrust is down only 2,500 pounds.

Landing Gear Flotation Options

The subject of landing gear flotation needs to be prefaced with a brief discussion of the terms used. The commonly used Load Classification Number (LCN) depends not only on the landing gear and aircraft weight, but also on the surface and subgrade beneath the surface. The use of LCG (Load Classification Group) is an attempt to get away from a single point estimate which is dependent on so many variables to represent flotation, and allow a simpler analysis of flexibility.

Figure 41 presents the LCG III landing gear configuration of the -313, -323, and -333 point designs. An analysis of its flotation characteristics is shown in Figure 42. The relationship between LCNs (on the vertical scale) and LCGs (horizontal bands) are in accordance with Defense Mapping Agency guidelines. (See Appendix E for a detailed description of the flotation analysis.) The aircraft weights of interest, (i.e., takeoff gross and normal landing) are shown for the three point designs incorporating this LCG III gear. The main points to be noted here are that the landing gear configuration of Figure 41 is indeed LCG III on subgrades ranging from poor to good, and that the LCG improves by about one group at the aircraft landing weight.

The option being examined is to decrease the flotation to LCG II. This landing gear configuration is shown in Figure 43. The new arrangement is four 4-

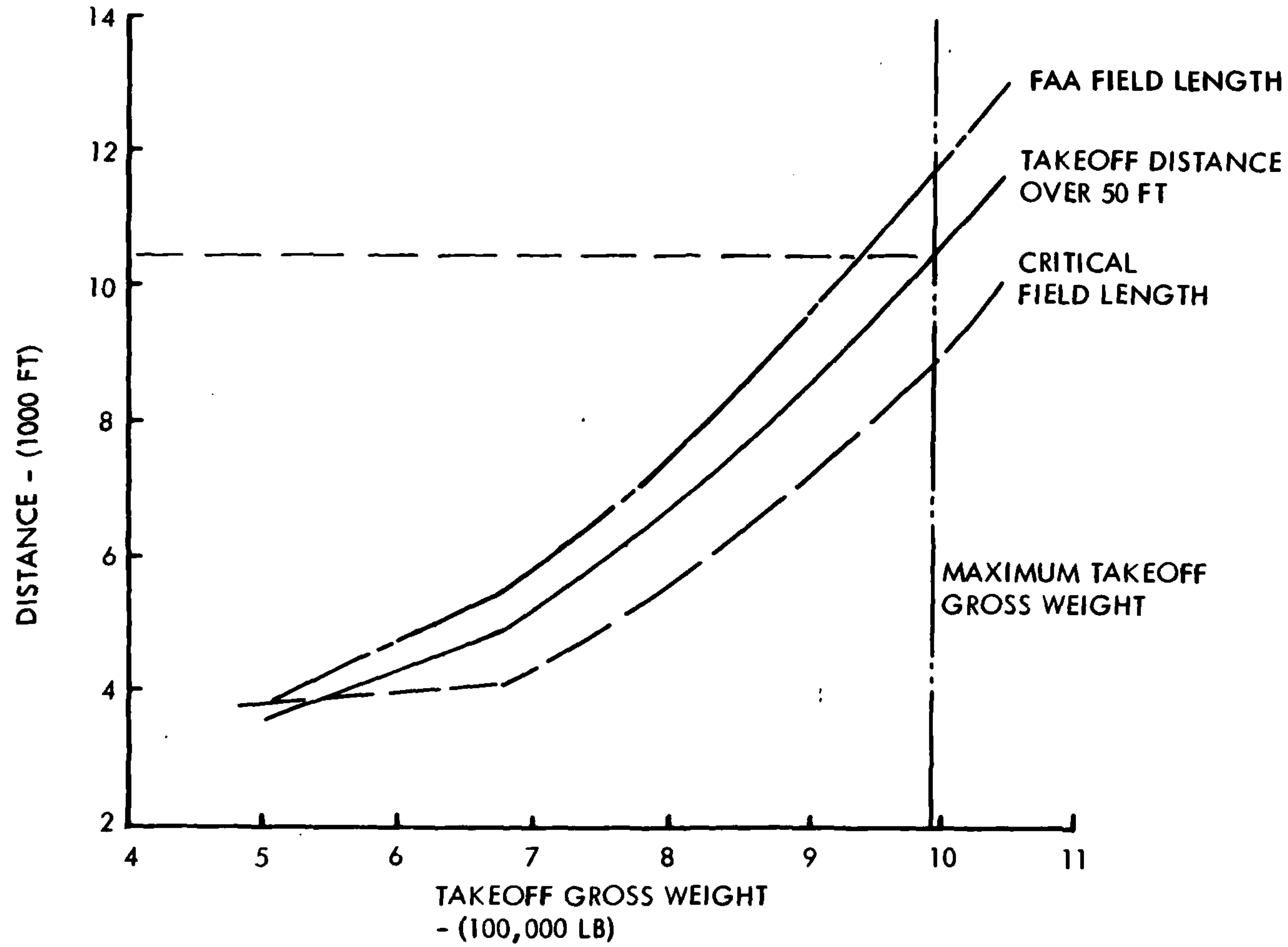


Figure 40. Takeoff Distance Characteristics: LGA-144-333

TABLE 20

EFFECT OF 10,500 FOOT TAKEOFF DISTANCE

PARAMETER	-323	-333	% CHANGE
• TAKEOFF DISTANCES (MGTOW) (FT)			
- OVER 50 FT	9,500	10,500	10.5
- CRITICAL FIELD LENGTH	7,950	8,820	10.9
- FAA FIELD LENGTH	10,630	11,770	10.7
• FIGURES OF MERIT			
- GROSS WEIGHT	1,004,700	996,500	- 0.8
- ENGINE THRUST	56,090	53,590	- 4.5
- T/W	.2223	.2151	- 3.2
- AMPR WEIGHT	321,770	320,450	- 0.4
- FUEL WEIGHT	250,510	246,000	- 1.8

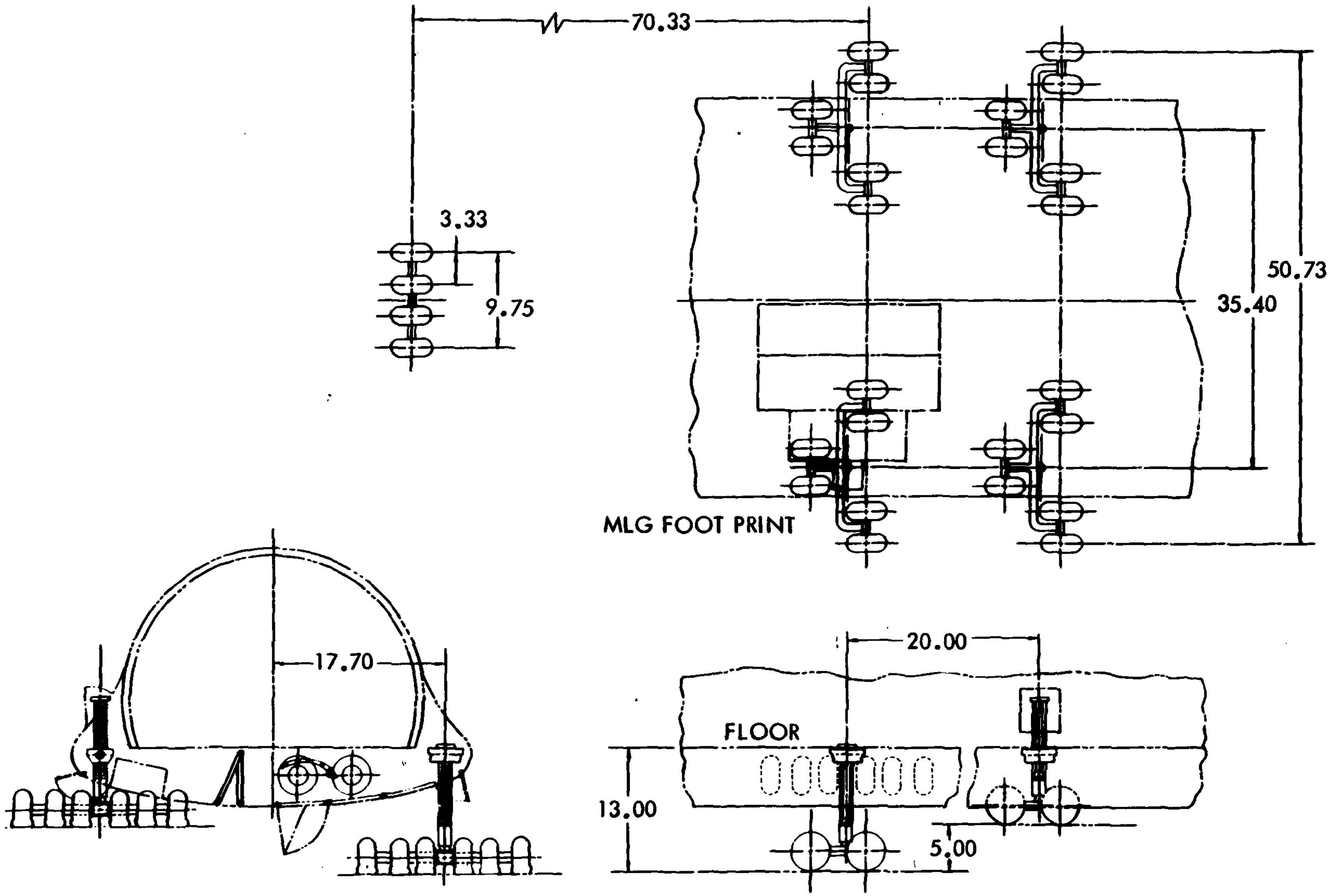


Figure 41. LCG III Landing Gear Arrangement

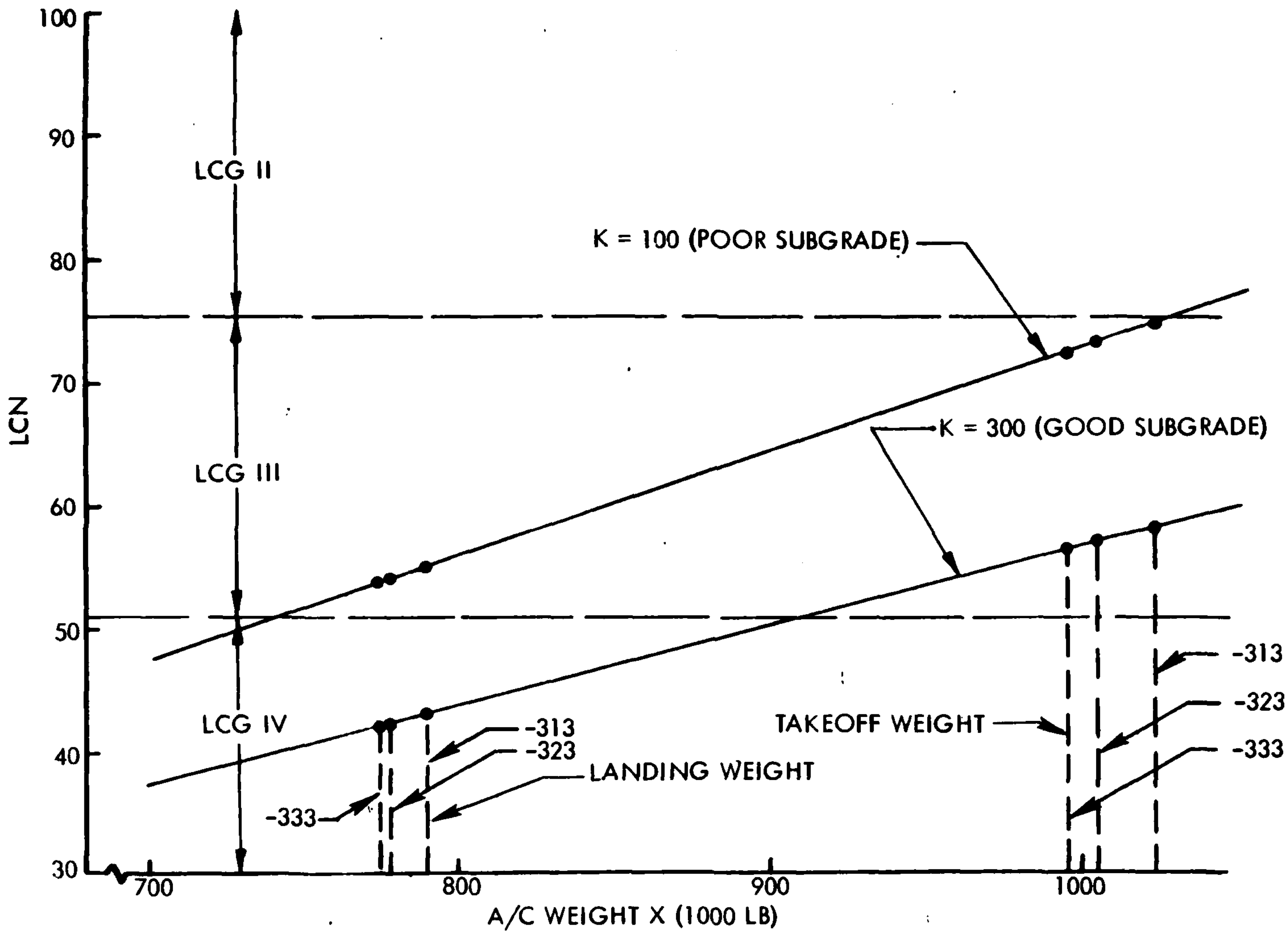


Figure 42. LCN Characteristics of LCG III Configurations

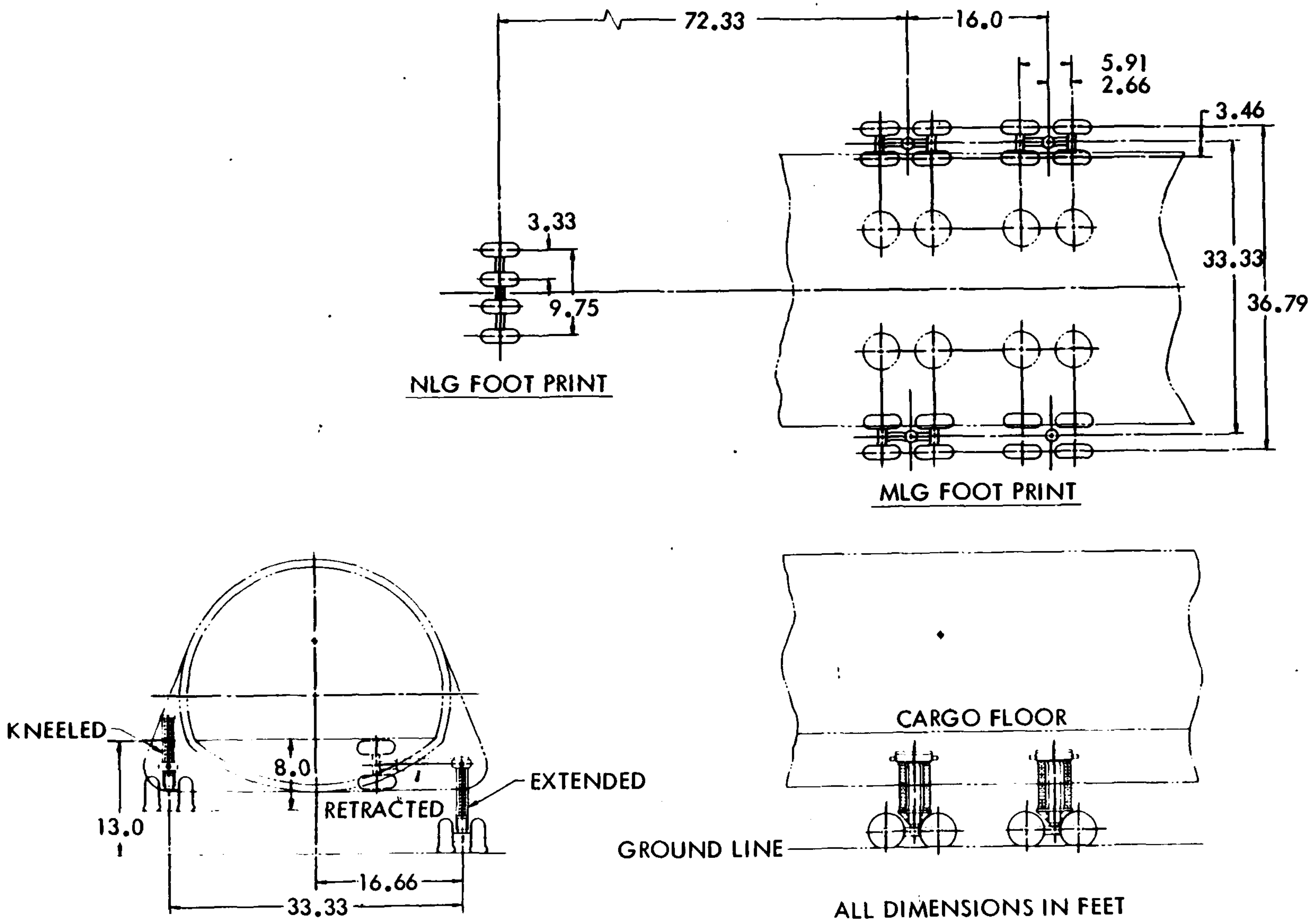


Figure 43. LCG II Landing Gear Arrangement

wheel bogies, which allow a simpler retraction scheme. The flotation analysis of Figure 44 confirms the same pattern as Figure 42, with the -322 and -332 being LCG II at takeoff and LCG III at landing.

The LCG II configuration option was applied to aircraft designed for both 9500 and 10,500-foot field lengths. The results of the resizing process are given by Table 21 and show that relaxing the flotation requirements saves about 2 percent in gross weight and fuel for the 9500-foot takeoff distance aircraft, and about 1.5 percent for the 10,500-foot aircraft.

Cost Analyses

The results of the cost analysis performed on these five Group III options are summarized in Figures 45, 46, and 47. The first figure shows military life-cycle costs as a function of takeoff distance for each LCG. The LCG III curve shows that increasing takeoff distance from 9500 to 10,500 feet decreases life-cycle costs about 2 percent, while decreasing it to 8000 feet increases costs about 3 percent. A similar trend is noted for the LCG II aircraft at a level 2 percent lower than that of the LCG III.

Figure 46 is a comparison of commercial DOCs for a 3500 nm stage length. The penalty for reducing takeoff distance below 9500 feet becomes even more pronounced here, approaching 8 percent. Furthermore, the benefits for increasing field length are becoming less noticeable, around 1 percent. Benefits for degrading flotation are also around 1 percent. The commercial unit prices are shown for the five point designs on Figure 47, and show similar trends.

Airfield Flexibility Analysis

To determine the merits of the takeoff distance and gear flotation options in operational use relative to the baseline, a detailed airfield analysis was performed, and is discussed in detail in Appendix I. The approach taken is to examine, for military considerations, both the APOD and APOE, and commercial airports for civil considerations.

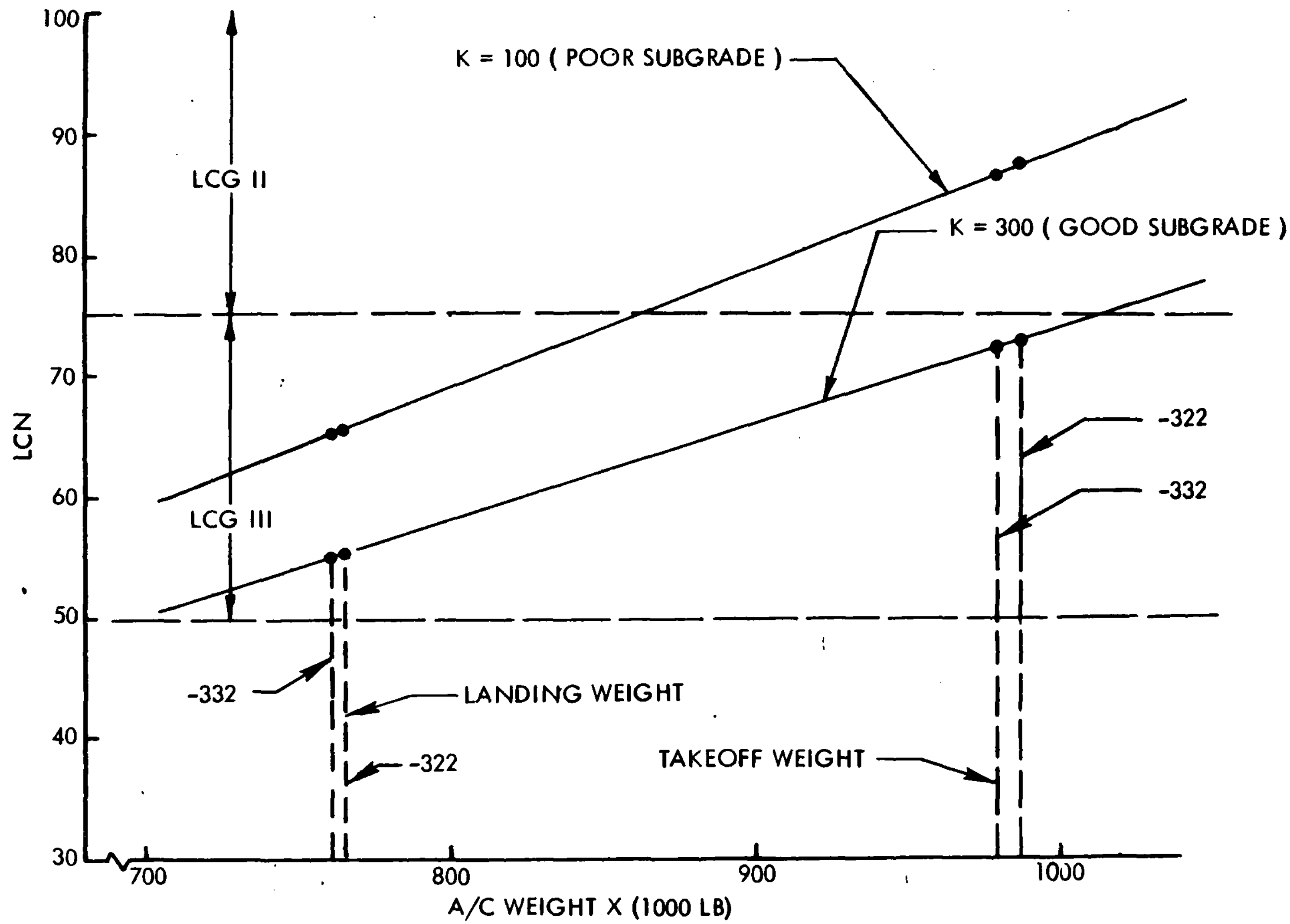


Figure 44. LCN Characteristics of LCG II Configurations

TABLE 21

EFFECT OF LANDING GEAR FLOTATION

● 9,500 FT TAKEOFF DISTANCE	LCG III (-323)	LCG II (-322)	% CHANGE
- GROSS WEIGHT (LB)	1,005,000	988,000	-2.0
- ENGINE THRUST (LB/ENG)	56,000	55,000	-1.8
- AMPR WEIGHT (LB)	322,000	313,000	-2.8
- BLOCK FUEL WEIGHT (LB)	226,000	222,000	-1.8

● 10,500 FT TAKEOFF DISTANCE	LCG III (-333)	LCG II (-332)	% CHANGE
- GROSS WEIGHT (LB)	996,000	980,000	-1.6
- ENGINE THRUST (LB/ENG)	54,000	53,000	-1.9
- AMPR WEIGHT (LB)	320,000	312,000	-2.5
- FUEL WEIGHT (LB)	222,000	219,000	-1.4

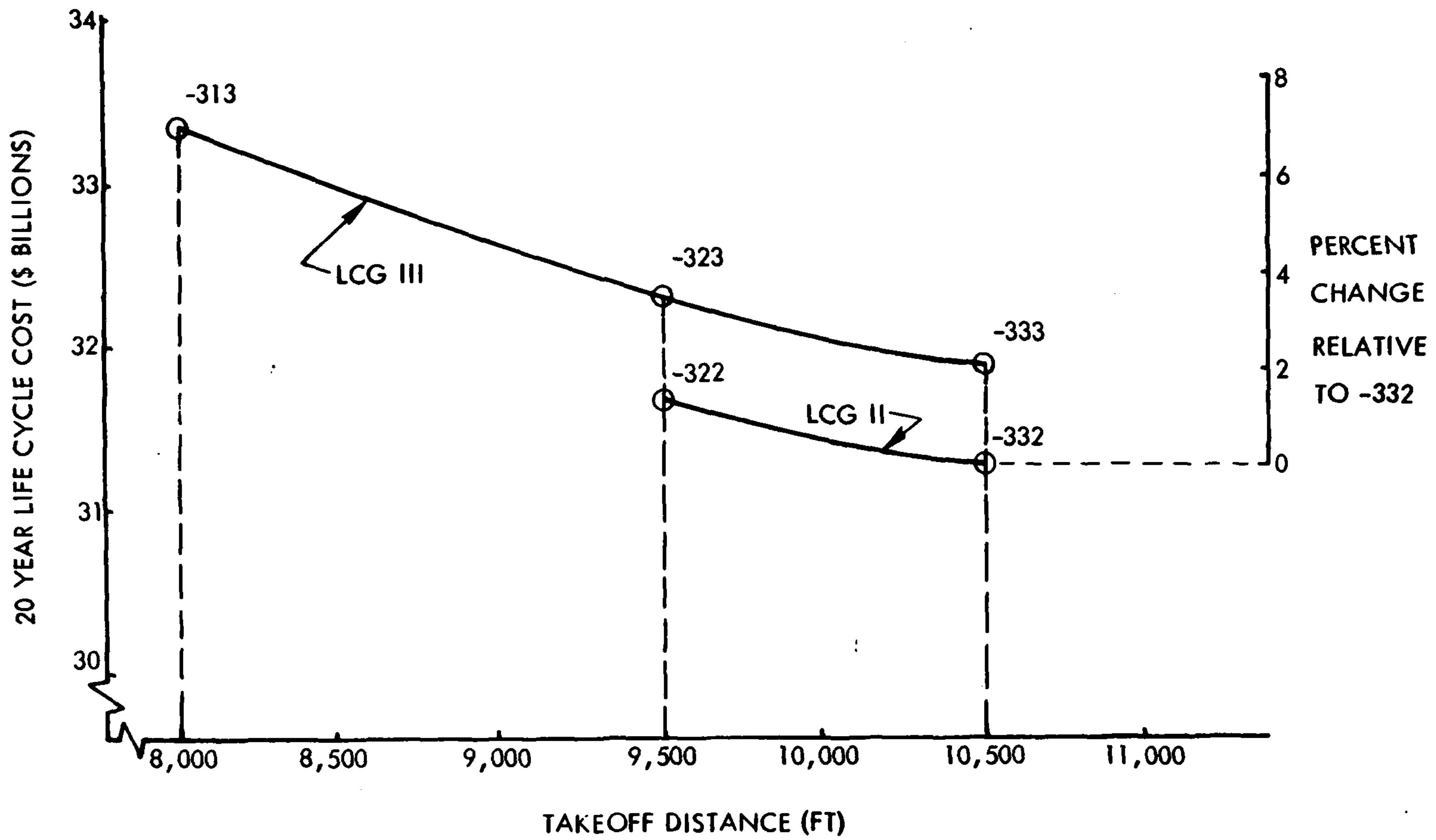


Figure 45. Group III Life Cycle Costs

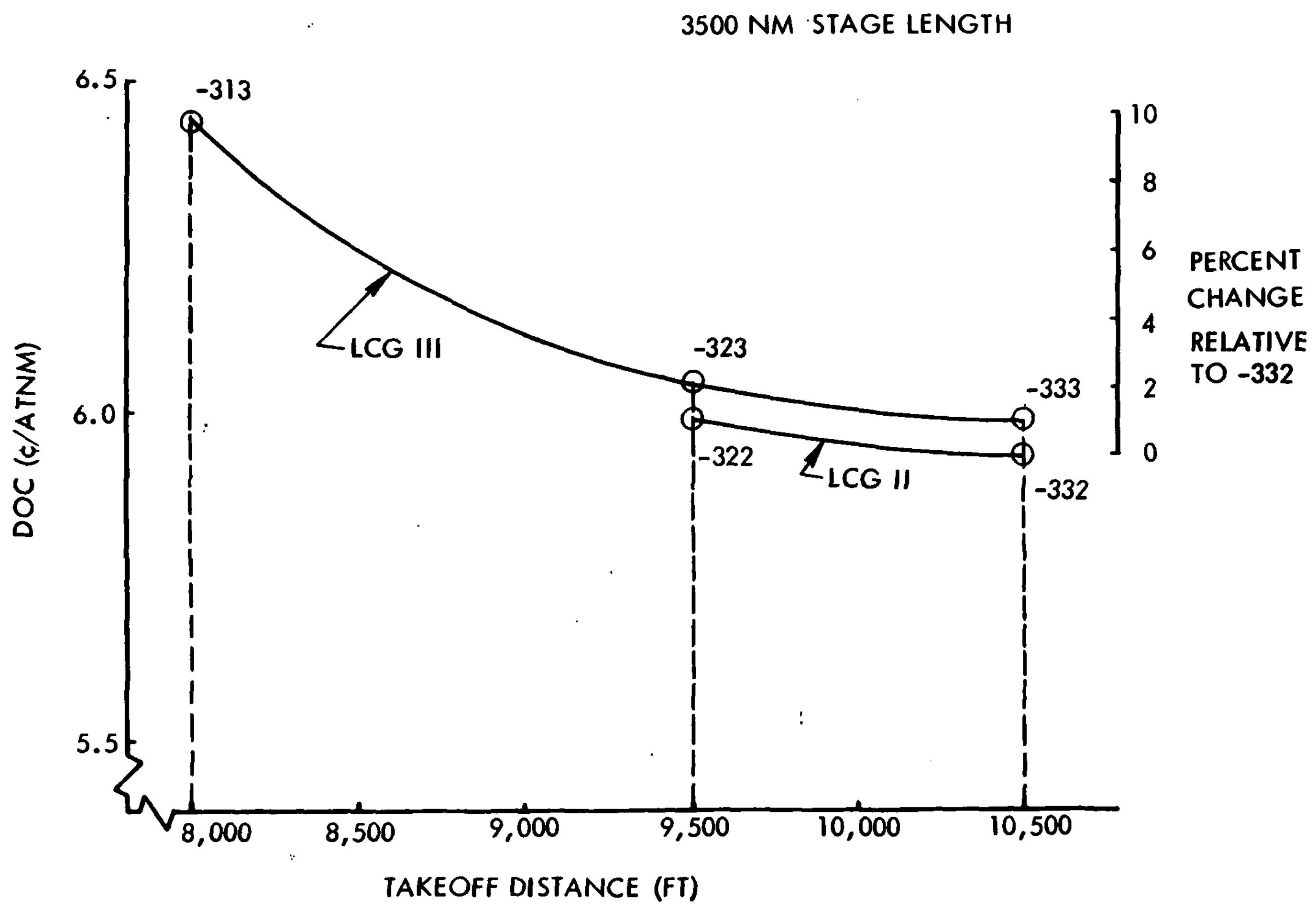


Figure 46. Group III DOCs

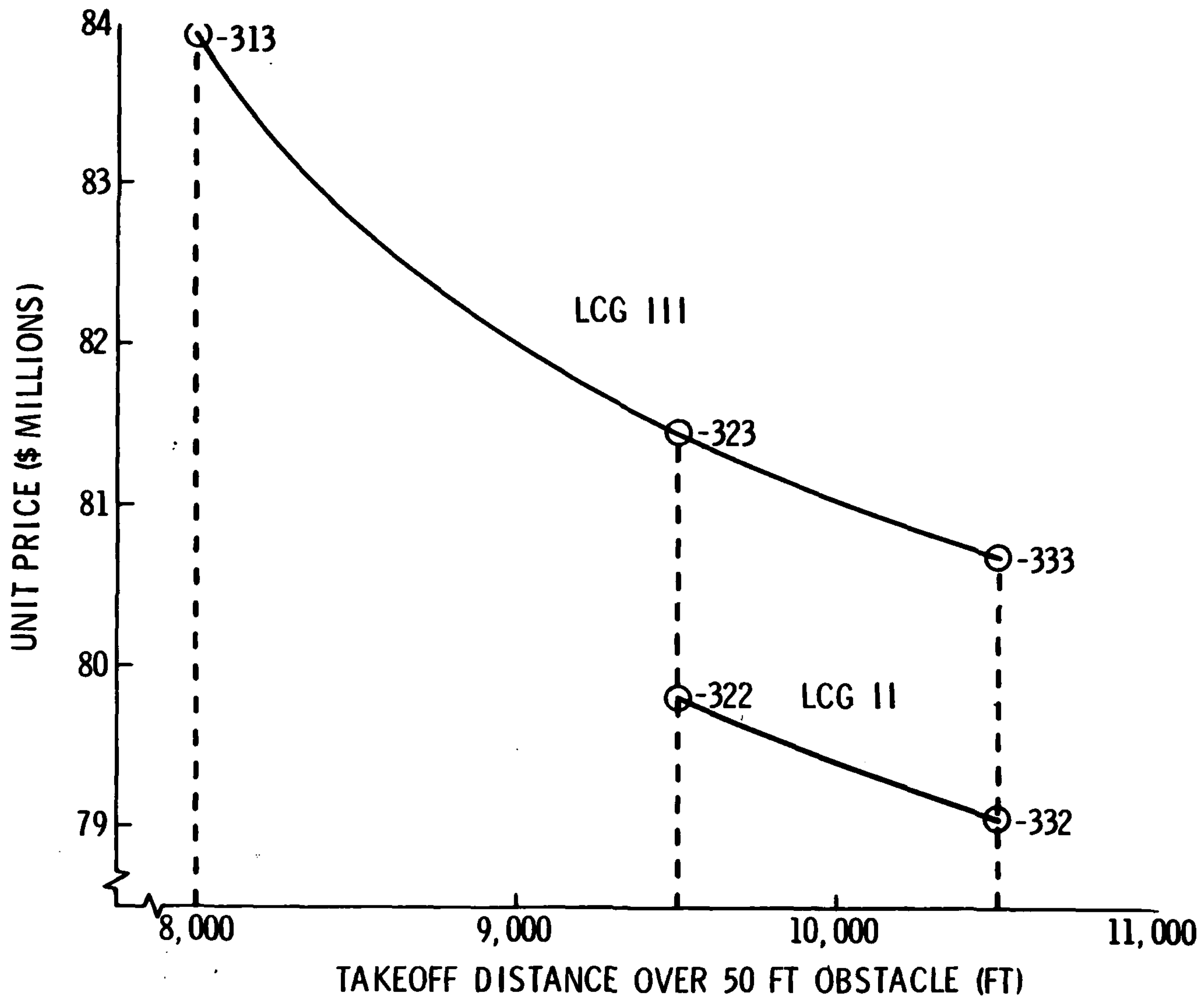


Figure 47. Group III Commercial Unit Prices

Airfields in West Germany, the Persian Gulf, and South Korea were sorted to find all those over 4000 feet long with suitable runway and taxiway widths and clearances. The analysis was used to find the geographic distribution of runways and parking spaces, broken down by runway length and LCG. Also determined were the percentage of the land area of the country as a function of distance from the nearest available airfield, and the number of airfields in terms of distance from the hostile border, for each LCG.

The 4000-foot field length was not an arbitrary choice. Figure 48 repeats the -323 baseline takeoff data and adds the curve of landing distance over the 50-foot obstacle as a function of aircraft weight. After the 4000 nm flight, the aircraft is landing with the 360,000-pound payload and reserve fuel, and can use a 3500-foot field. Takeoff performance with full fuel and no payload is about 4000 feet. Table 22 confirms the fact that all five of these Group III aircraft have similar APOD performance characteristics, leading to the interesting conclusion that design takeoff distance has little if any effect on APOD performance, assuming retrograde payloads are relatively light.

Thus, LCG plays the more important role in choosing among the Group III options from the standpoint of APOD flexibility. An example of the data in Appendix I is given in Table 23. Here, for the West Germany analysis, the effect of LCG on the figures of merit introduced earlier is shown to be on the order of a 50 percent reduction in flexibility by going to an LCG II landing gear. The reduction in real terms for West Germany is from 64 suitable airfields to 34; however, in South Korea, the reduction is from 20 to just 11 suitable airfields.

For the APOE analysis, the approach is to identify the suitable airfields within a one-day's march of each army post. The results in terms of field length restrictions are best given by Figure 49. Extensibility is defined here as an indication of the longest possible runway subject to environmental, geographical, and other physical constraints, as explained in Appendix I. As Figure 49 shows, if extensibility is considered, runway length does not appear to be a restriction for the ACMA. However, degrading the LCG from III to II causes a loss of about two-thirds of the available runways. Table 24

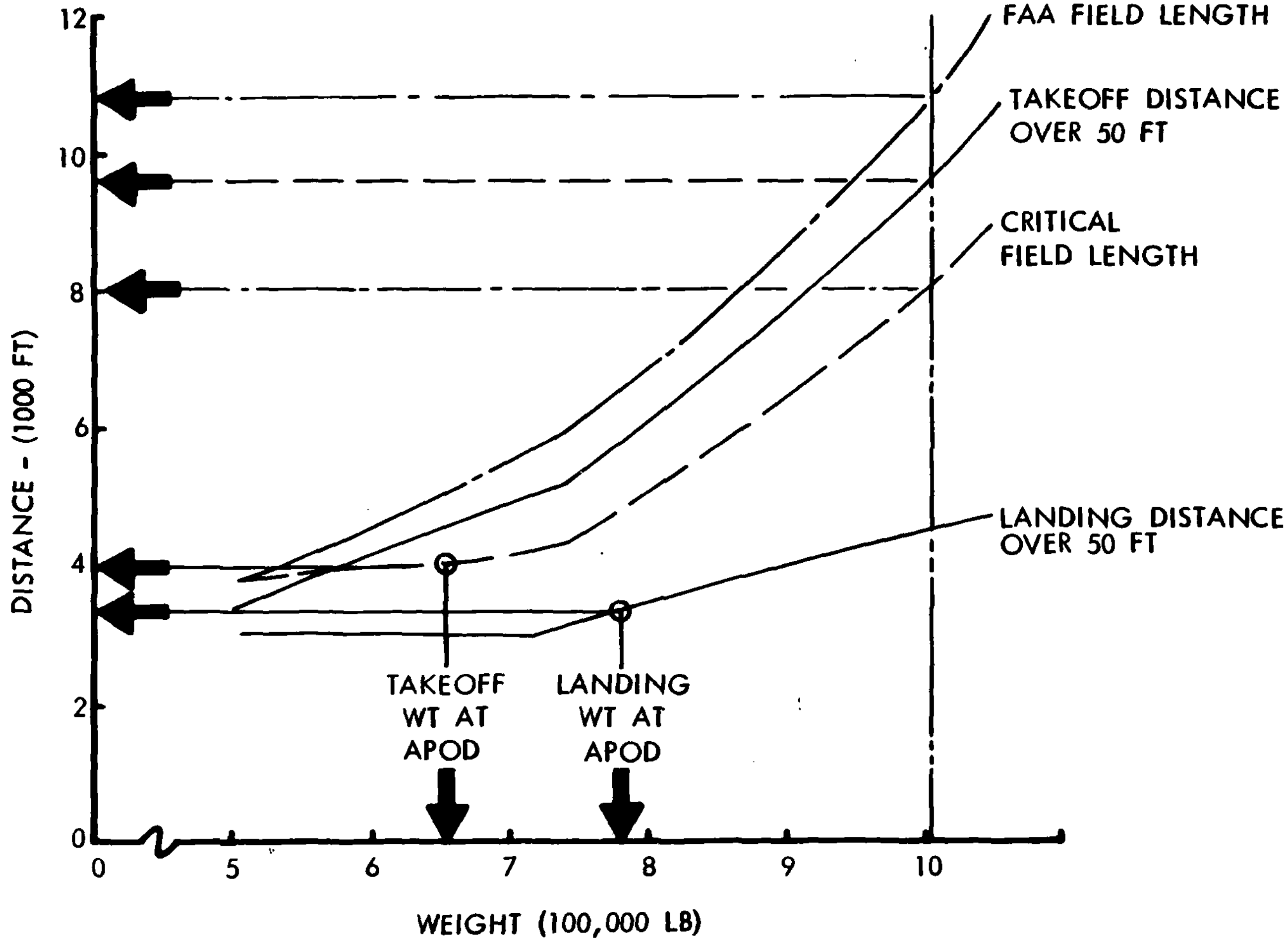


Figure 48. Field Performance: LGA-144-323

TABLE 22
GROUP III APOD PERFORMANCE

MODEL NUMBER	LANDING DISTANCE (FT)	CRITICAL FIELD LENGTH (FT)	LANDING DISTANCE (FT)
PAYLOAD	MAXIMUM	ZERO	MAXIMUM
FUEL LOAD	RESERVES	MISSION	ONE-HALF MISSION
LGA-144-313	3,760	3,950	3,850
-323	3,520	4,000	3,850
-333	3,700	4,040	4,000
-322	3,500	4,130	3,810
-332	3,610	3,930	3,950

TABLE 23
IMPACT OF LCG ON APOD FLEXIBILITY

	DESIGN LCG		
	III	II	% CHANGE
• NUMBER OF SUITABLE AIRFIELDS	64	34	-47%
• CORRESPONDING NUMBER OF AVAILABLE PARKING SPACES	421	283	-33%
• PERCENT OF COUNTRY WITHIN 100 KM OF AN AVAILABLE APOD	97	95	-2%
• NUMBER OF AIRFIELDS AVAILABLE AFTER A 100 KM PENETRATION	50	26	-48%
• NUMBER OF PARKING SPACES AVAILABLE AFTER A 100 KM PENETRATION	341	208	-39%

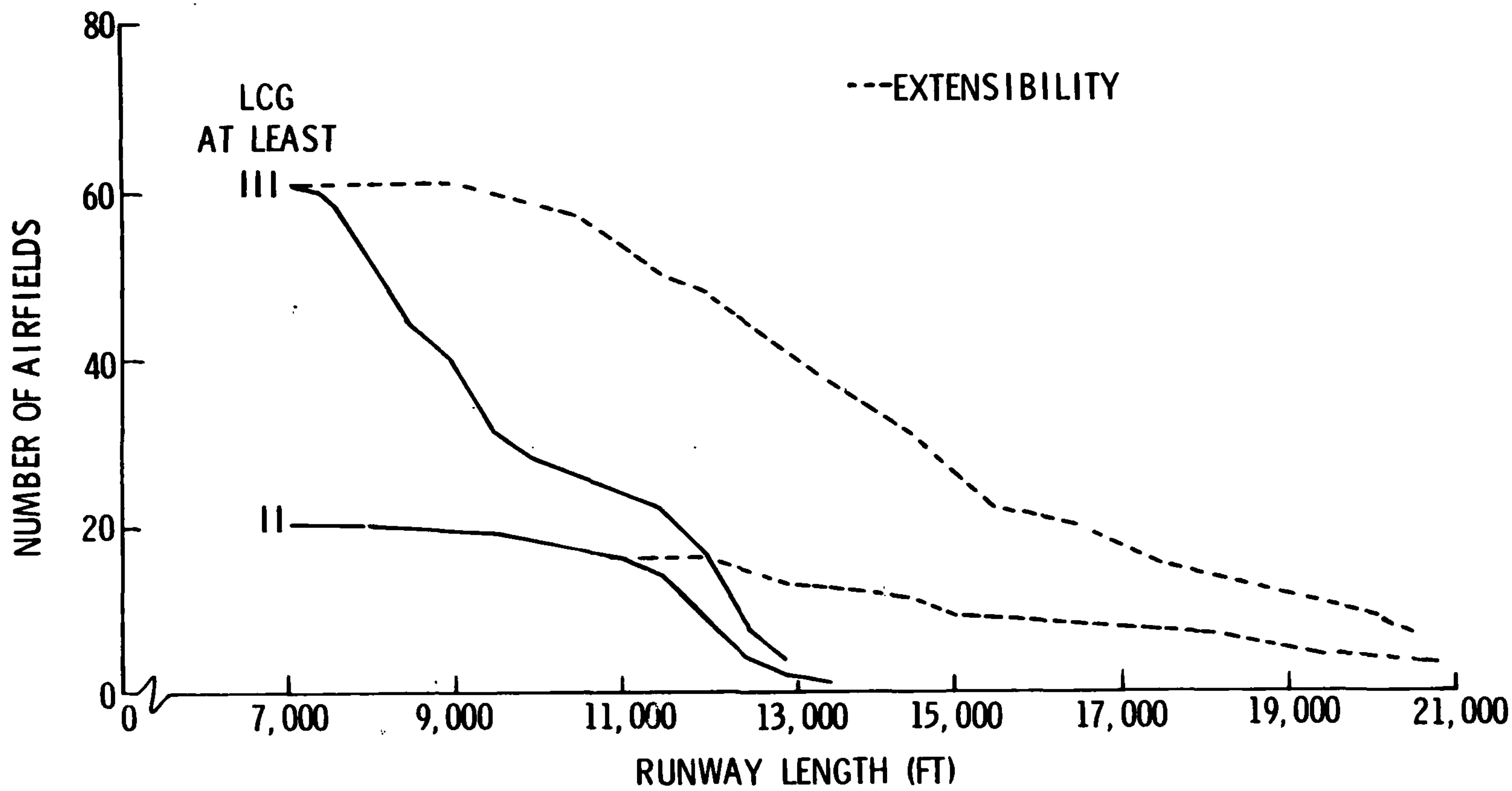


Figure 49. Runway Availability and Extensibility - APOE's

TABLE 24

CLOSEST SUITABLE APOE TO ARMY POSTS

ARMY POSTS	ROAD DISTANCE (NM) A/C LCG III	A/C LCG II
Ft. Hood	75	75
Ft. Lewis	8	264
Ft. Stewart	30	30
Ft. Polk	49	49
Ft. Carson	0	333
Ft. Campbell	0	162
Ft. Bragg	68	69
Ft. Riley	64	116
Ft. Ord	53	86
AVERAGE	39	132

emphasizes this point by showing that going from LCG III to II also causes a considerably longer road march to get to the APOE from the army posts.

The commercial flexibility analysis follows a similar scheme of identifying commercial airports around the world and sorting them by field length and LCG. The resulting pattern is shown in Figure 50. Here again, if extensibility is considered, the number of runways for a given LCG remains nearly constant out to about 11,000 feet, and degrading landing gear flotation again causes a loss in flexibility of about 50 percent.

Summary Comparisons

The summary comparison format is used in Tables 25 and 26 to recap the findings with regard to takeoff distance and landing gear flotation. The takeoff distance comparison of the first table presents data for the -323 baseline and percent changes for the 8000 and 10,500-foot options, the -313 and -333, respectively. Note that requiring the 8000-foot takeoff distance is very expensive in terms of military life-cycle costs and commercial economics, and, according to the flexibility analysis, is probably not necessary; however, a substantial retrograde requirement would weaken this argument. The benefits of relaxing the takeoff distance requirement to 10,500 feet are about one percent for both the military and civil operators; however, civil runway extensibility becomes almost a requirement, especially since FAA field length increases to almost 12,000 feet.

The issue of LCG is addressed by Table 26, where the second column is absolute data and the third column is percent change for the -322 LCG II gear relative to the -323 baseline LCG III gear. The military benefits are about two percent for higher payload fraction with accompanying lower life-cycle costs. The penalties in flexibility are considerable and military planners will have to carefully weigh the tradeoff. Similarly, the commercial benefits are between 1.5 and 2.0 percent in operating economics, but the LCG II gear prevents the use of about 50 percent of the available airports by a ACMA commercial air freighter.

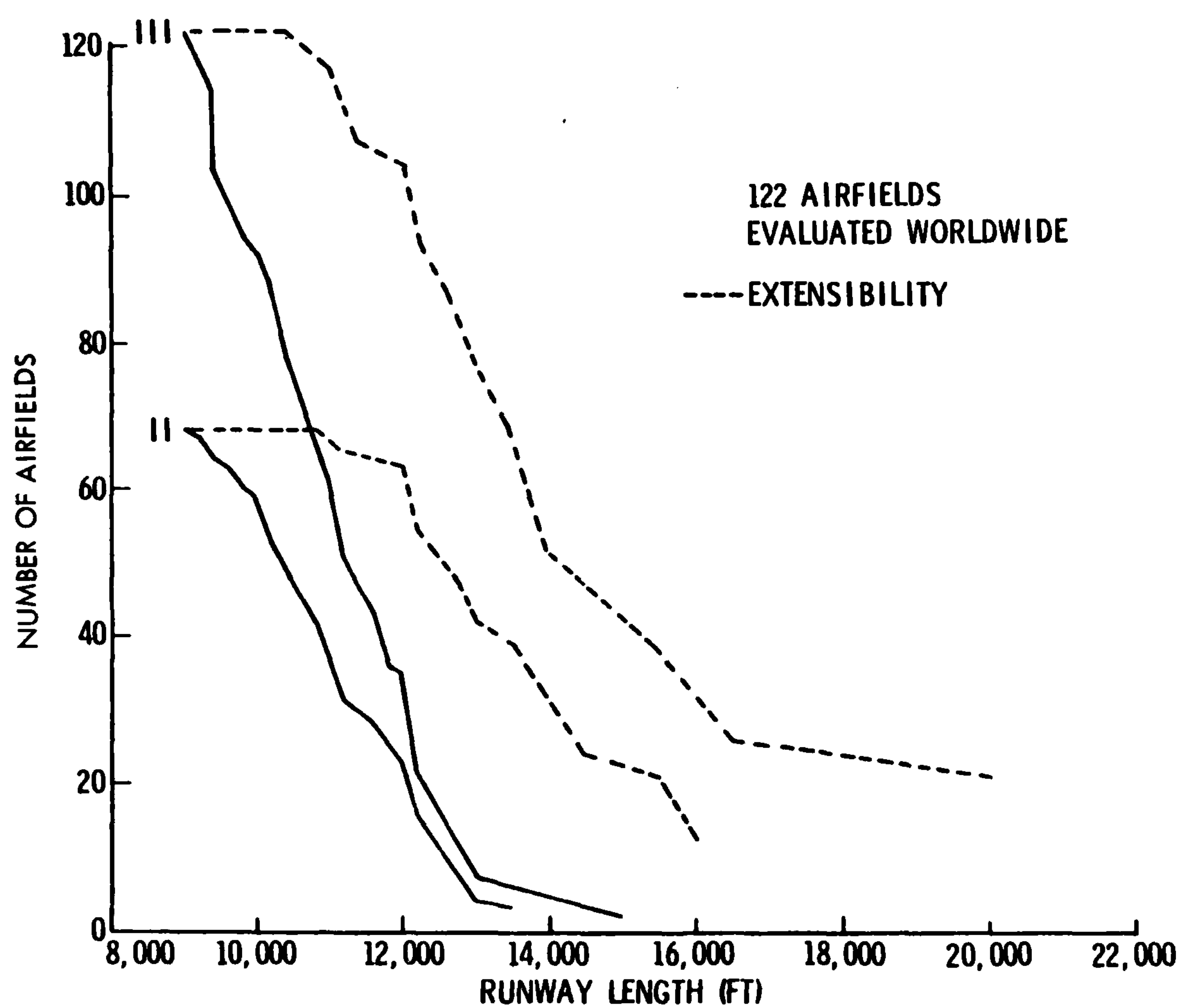


Figure 50. Commercial Runway Availability and Extensibility

TABLE 25

TAKEOFF DISTANCE SUMMARY COMPARISON

MODEL NUMBER	LGA-144-323	LGA-144-313	LGA-144-333
LCG	III	III	III
Takeoff Distance Over 50 Ft. (Ft)	9,500	8,000	10,500
MILITARY			
Payload Fraction	0.358	-2.0%	+0.8%
Life-Cycle Costs ($ Bil)	32.3	+3.6%	-1.2%
Critical Field Length (Ft)	7,950	6,630	8,820
Landing Distance Over 50 Ft. (Ft)	3,520	3,760	3,700
COMMERCIAL			
Fuel Economy (TNM/Gal)	21.2	-8.0%	+1.3%
Unit Price ($Mil)	81.5	+3.0%	-1.0%
DOC (¢/ATNM)	6.04	+6.6%	-1.2%
DOC + ROI (¢/ATNM)	10.82	+5.9%	-1.2%
FAA Field Length (Ft)	10,630	8,920	11,770

TABLE 26

LANDING GEAR FLOTATION SUMMARY COMPARISON

MODEL NUMBER LCG Takeoff Distance Over 50 Ft. (Ft)	LGA-144-323 III 9,500	LGA-144-322 II 9,500	LGA-144-322 II 9,500
MILITARY			
Payload Fraction	0.358	0.364	+2.0%
Life-Cycle Costs ($ Bil)	32.3	30.9	-2.0%
APOD Flexibility*	20	11	-45%
APOE Flexibility**	39	139	+240%
COMMERCIAL			
Fuel Economy (TNM/Gal)	21.2	21.5	+1.5%
Unit Price ($ Mil)	81.5	79.8	-2.0%
DOC (¢/ATNM)	6.04	5.94	-1.7%
DOC + ROI (¢/ATNM)	10.82	10.63	-1.8%
Commercial Flexibility ***	120	68	-43%

*Number of Suitable Airfields (South Korea)

**Average Road Distance to Closest Airfield (nm)

***Number of Suitable Airfields (Worldwide)

NOISE CHARACTERISTICS/CLIMB GRADIENT

Civil certification of the ACMA will require that it have a 3 percent second segment climb gradient and meet FAR Part 36, Stage 3 limits on the takeoff, approach, and sideline noise of the aircraft. The requirements and the analysis are detailed in Appendix E; therefore, the discussion here will only summarize the results.

The noise characteristics of the untreated aircraft are presented in Table 27. The -343, -353, and -363 are designed for the takeoff distance requirements of 8000, 9500, and 10,500 feet, respectively, and the noise data in this table include the effect of the 3 percent climb gradient. The FAR limits on noise and the -323 baseline noise characteristics are also shown. The effect of takeoff distance on noise measurements for takeoff flyover and takeoff sideline are interesting because they move opposite to each other. The shorter takeoff distance increases the aircraft's altitude over the flyover measurement point, thus decreasing flyover noise; but the larger engines required by that option increase sideline noise. The longer takeoff distance aircraft shows the opposite effect. The worst noise problem, however, is the approach, where the limits are exceeded by all of the untreated aircraft by 10 EPNdB.

Only one of the point designs, the -353, was carried through the last stage of the analysis. The treatment required to meet FAR 36 is estimated to be 800 pounds per nacelle for noise suppression materials, an engine fuel consumption penalty of 0.5 percent, and a thrust loss of 0.5 percent. The net result is a design which meets FAR 36, as shown in Table 28. The physical penalties relative to the untreated -323 baseline are a 1.1 percent higher gross weight and 2.9 percent larger engines. In economic terms, this translates to 2.5 percent higher military life cycle costs and 1.5 percent higher commercial DOC for compliance with the noise and climb gradient regulations.

TABLE 27

NOISE CHARACTERISTICS WITHOUT TREATMENT

		NOISE LEVELS - EPNdB		
	TAKEOFF DISTANCE	TAKEOFF FLYOVER	TAKEOFF SIDELINE	APPROACH
FAR PART 36 STAGE 3 LIMITS		106.0	103.0	105.0
LGA-144-343	8,000 FT	106.4	103.1	116.0
LGA-144-353	9,500 FT	107.8	102.7	115.4
LGA-144-363	10,500 FT	108.7	102.5	115.3
LGA-144-323	9,500 FT	108.2	102.8	115.5

TABLE 28

EFFECT OF FAR PART 36 COMPLIANCE

COMPLIANCE COMPARISON	TAKEOFF FLYOVER	TAKEOFF SIDELINE	APPROACH
- FAR PART 36 STAGE 3	106.0 EPNdB	103.0 EPNdB	105.0 EPNdB
- LGA-144-353	102.4	99.1	104.6
	- 323	- 353	CHANGE
DESIGN CHARACTERISTICS			
- FAR PART 36 COMPLIANCE	NO	YES	-
- CLIMB GRADIENT	2.5%	3.0%	-
- FAA FIELD LENGTH, FT	10,632	10,613	-0.2%
FIGURES OF MERIT (LB)			
- GROSS WEIGHT	1,004,700	1,016,100	+1.1%
- ENGINE THRUST, UNINSTALLED	56,100	57,700	+2.9%
- AMPR WEIGHT	321,800	326,300	+1.4%
- BLOCK FUEL WEIGHT	225,800	227,800	+0.9%
ECONOMICS			
- LCC ($ BILLIONS)	32.2	33.1	+2.5%
- DOC (¢/ATNM)	5.90	5.99	+1.5%
- DOC+ROI (¢/ATNM)	10.48	10.66	+1.8%

VII. GROUP IV SUMMARY RESULTS

The Group IV analyses are concerned with the design features of cargo compartment envelope (i.e., maximum height), pressurization requirements, maximum structural payload, service life specification, and passenger provisions. The options considered for each of these features are given on the foldout page at the back of this volume. They correspond to the qualitative assessment except for the passenger provisions, which are modified as explained later in this section.

Several changes were made to the -223 in the process of its becoming the baseline for the Group IV analysis, the -400. One important change, shown in Figure 51 was made to allow 10-foot high containers to be carried in the outboard cargo lanes with 6 inches clearance to aircraft structure. The outside radius was increased and the center of this radius was translated up to get the required height at the sidewall. The cockpit and relief crew areas, Figure 52, were redesigned and raised one foot higher relative to the cargo compartment floor to give better cockpit visibility and to allow more height for vehicle cresting. A general arrangement of the -400 baseline is shown on Figure 53. A complete description of all the Group IV point designs can be found in Appendix F.

CARGO COMPARTMENT ENVELOPE

The purpose of this analysis was to determine the implications of requiring outsized cargo carrying capability on a three-stick wide ACMA. The height of the cargo compartment in the -400 baseline is nominally 13.5 feet, although another foot is available for cresting at the forward ramp, as discussed above. The option being examined is a cargo compartment 11 feet high, except again, another foot of clearance is provided at the forward aperture for vehicle cresting. The 11-foot height is suitable for the tallest projected container and the XM-1 tank, but does eliminate some taller military vehicles, as discussed in Volume III.

The fuselage shape for the -411, shown in Figure 54, consists of two pairs of circular arcs, tangent at their intersections, forming an ellipse-like shape

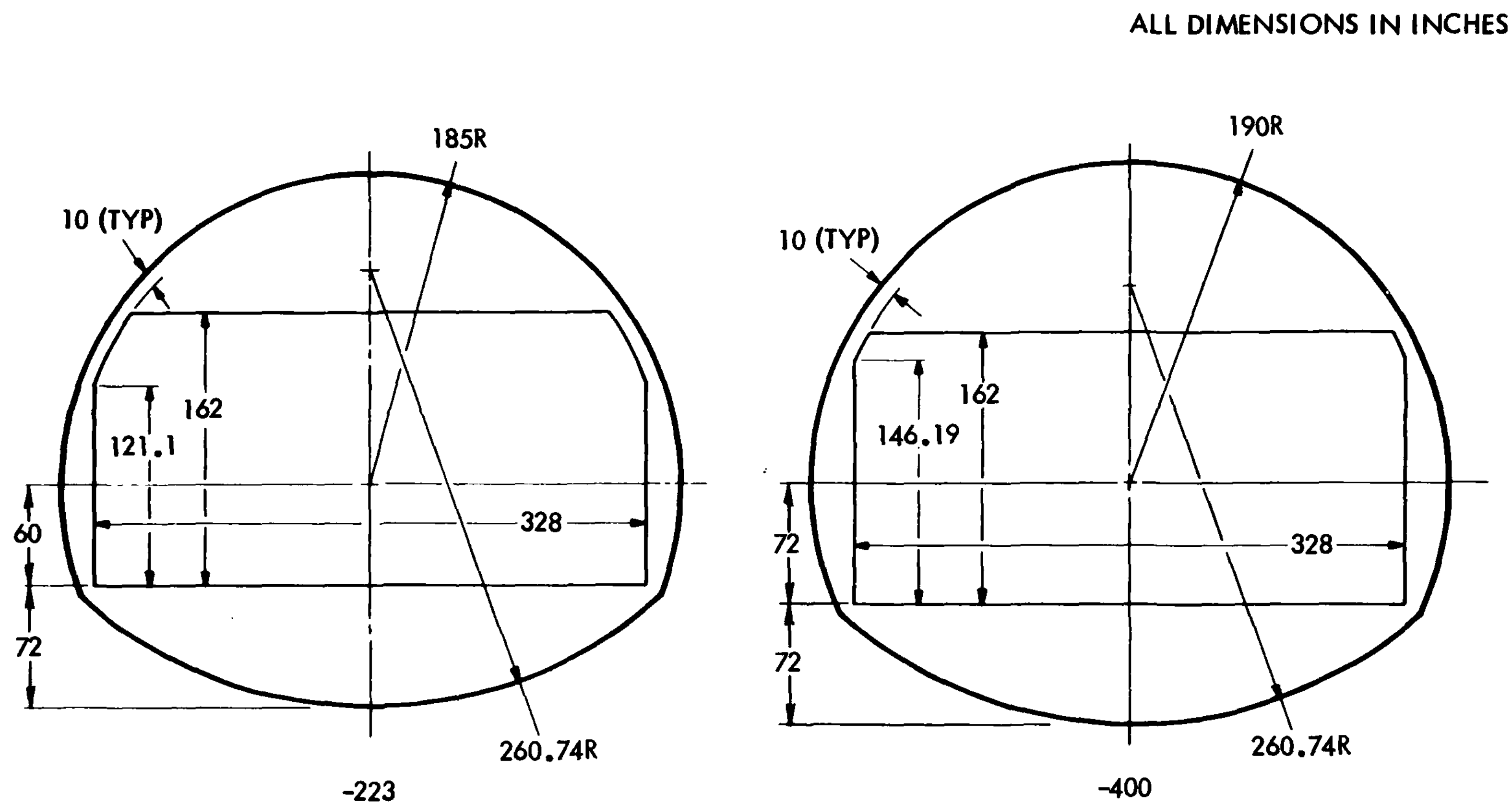


Figure 51. Cross Section Comparison: -223 vs -400

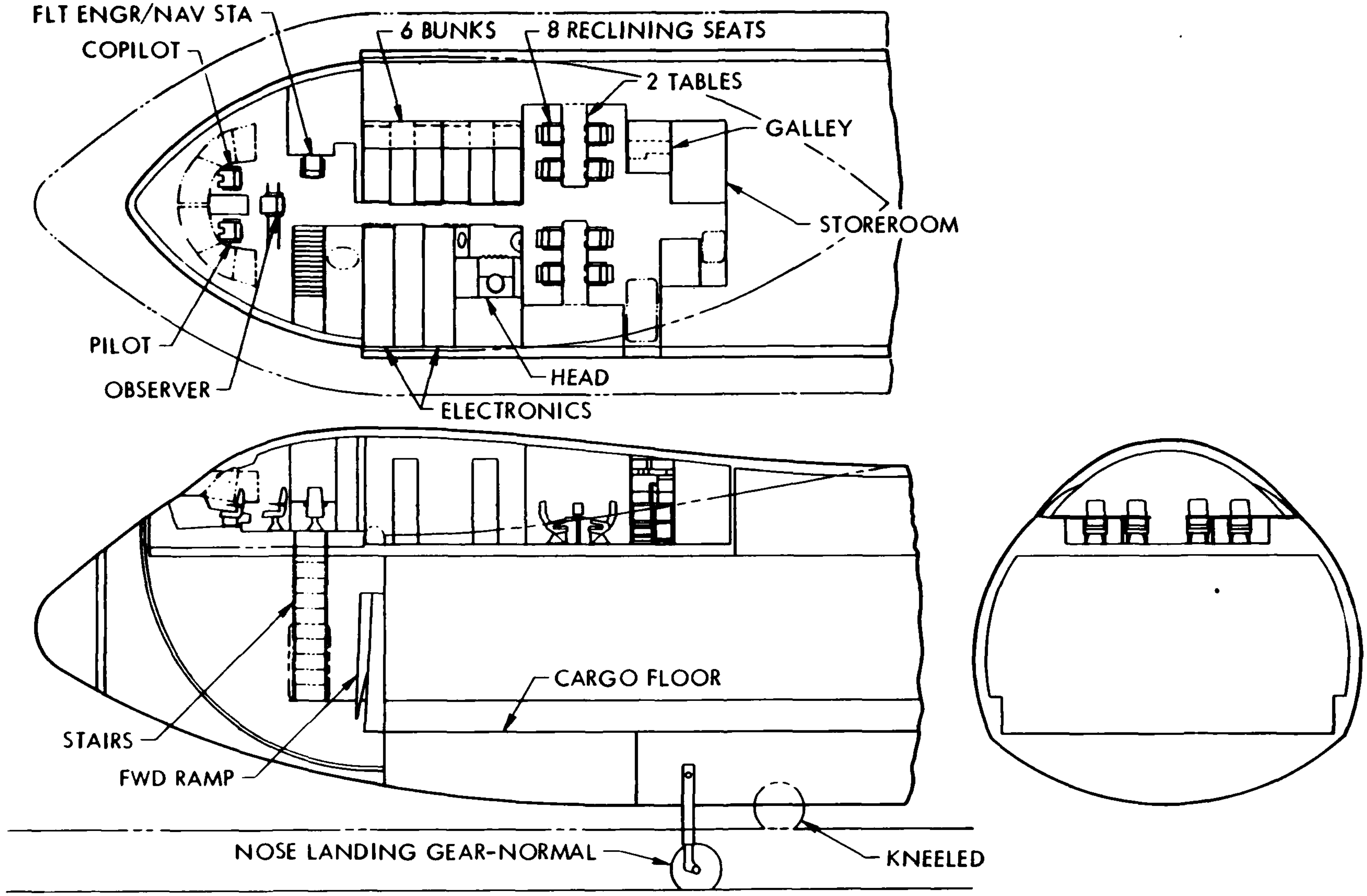


Figure 52. Forward Fuselage Inboard Profile: LGA-144-400

CRUISE MACH NO.	0.78
DESIGN PAYLOAD	390,000 LB
DESIGN RANGE	4,000 N.MI.
OPERATING WT.	394,800 LB
MAX. GROSS WT.	1,038,600 LB
ASPECT RATIO	10.1
WING LOADING	129.4 PSF
THRUST PER ENGINE	58,300 LB

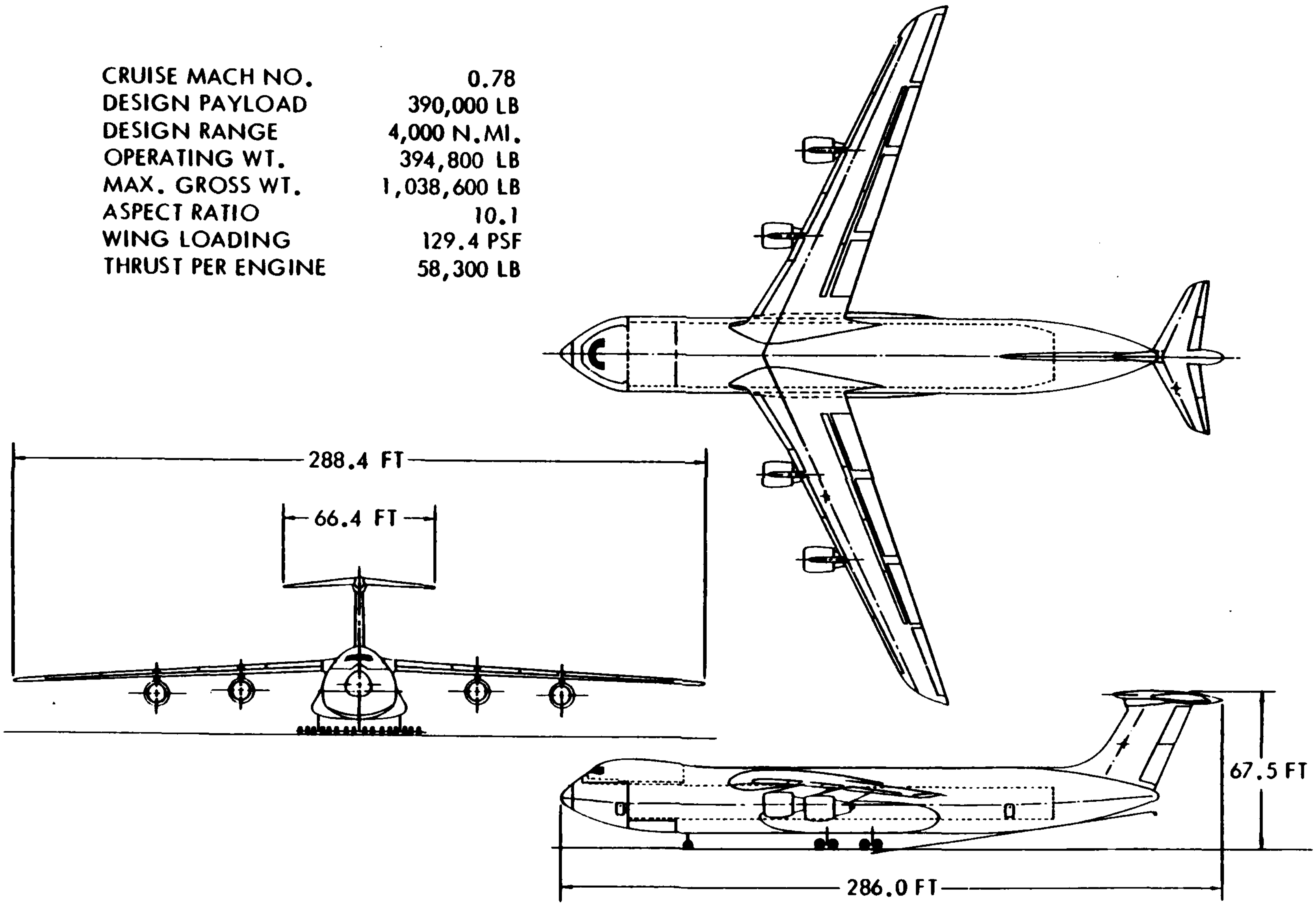


Figure 53. General Arrangement: LGA-144-400

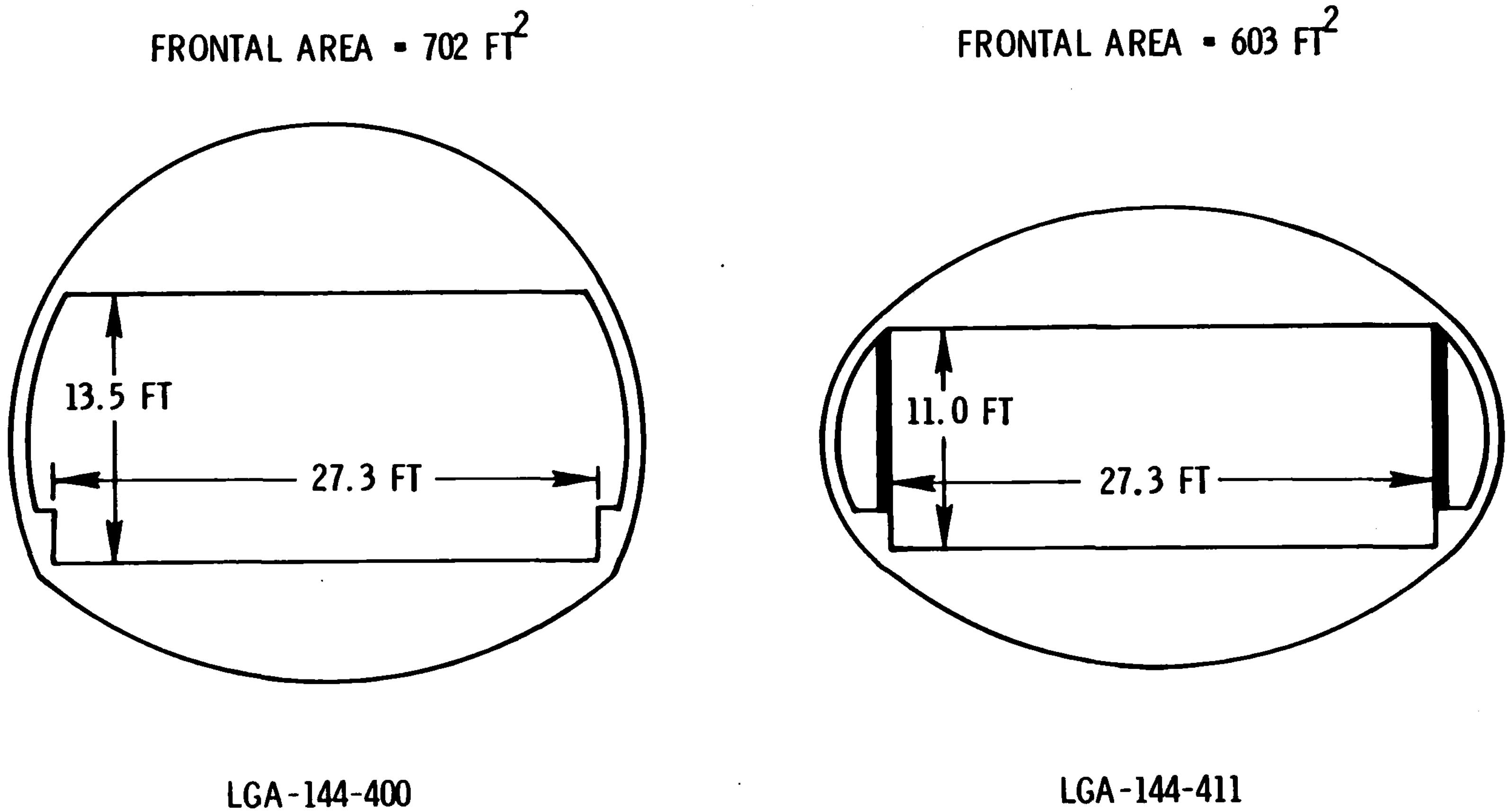


Figure 54. Cross Section Comparison: -400 and -411

around the cargo compartment. This new shape has a cross-sectional area 14 percent smaller than the -400. But when the same fineness ratios as the baseline are used to design a forebody and an aftbody, the total fuselage wetted area is only 2.8 percent less, although the fuselage pressurized volume is down 10.5 percent. Structural analysis showed that large tension ties are required between the upper and lower halves of the fuselage to react pressurization loads. Aerodynamic analysis showed that the increased plan to side area ratio led to poorer drag characteristics. Thus, the optimized -411 aircraft, shown in Figure 55, is actually heavier than the baseline, as shown in Table 29.

While these results brand the -411 as an uninteresting candidate aircraft, a military flexibility analysis was performed to determine the implications of a restriction in cargo compartment height to 11 feet for the transport of various division types. Figure 56 presents the actual tons and the percentage of total weights not loaded on the -411 for a number of Army divisions and an Air Force bare base unit. One interesting point is that 1.3 percent of the total division weight can mean as little as 144 tons or as much as 701 tons depending on the makeup of the division. The fact that Army divisions are getting taller is indicated by the bar for the 1990 mechanized division, which shows that the weight of vehicles not loaded increases by a factor of four over today's mechanized division.

A summary comparison for the reduced cargo compartment height design feature is given by Table 30. For the military, it means a 0.3 percent lower life-cycle cost at the price of a loss in flexibility. Interestingly enough, the commercial operator, who presumably might oppose outsized capability in a ACMA, strongly favors the baseline configuration; going to the -411 would cost him more in unit price, fuel economy, and DOC.

CARGO COMPARTMENT PRESSURIZATION

An analysis was performed on the effects of reducing the cabin pressure in the cargo compartment from 8000 feet to 18,000 feet at a 40,000-foot flight altitude. This option was applied to both the -400 baseline fuselage as well as the oval-shaped -411 fuselage.

CRUISE MACH NO.	0.78
DESIGN PAYLOAD	390,000 LB
DESIGN RANGE	4,000 NM
OPERATING WT	395,000 LB
MAX GROSS WT	1,041,000 LB
ASPECT RATIO	10.1
WING LOADING	129.4 PSF
THRUST PER ENGINE	58,700 LB

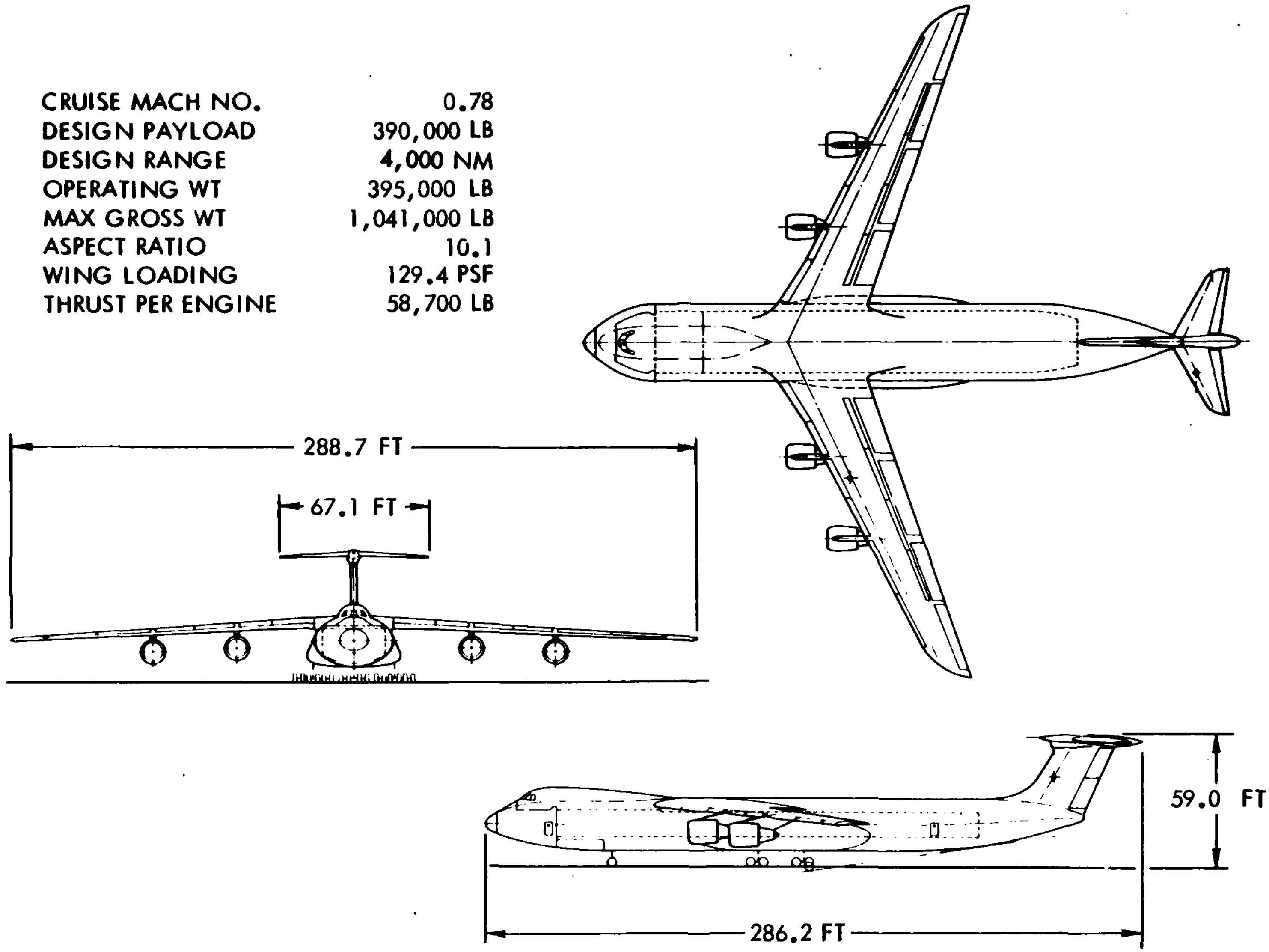


Figure 55. General Arrangement: LGA-144-411

TABLE 29

EFFECTS OF REDUCED HEIGHT CARGO COMPARTMENT

PARAMETER	-400	-411	% CHANGE
● FUSELAGE CHANGE			
- CARGO COMP'T HT - FT	13.5	11.0	-18.5
- CROSS SECTION AREA - FT^2	702	603	-14.1
- WETTED AREA - FT^2	21,500	20,900	-2.8
- PRESSURIZED VOLUME - FT^3	149,200	133,600	-10.5
● FIGURES OF MERIT			
- GROSS WEIGHT - LBS	1,038,600	1,041,000	0.2
- AMPR WT - LBS	319,600	319,700	0.0
- BLOCK FUEL - LBS	228,700	230,600	0.8

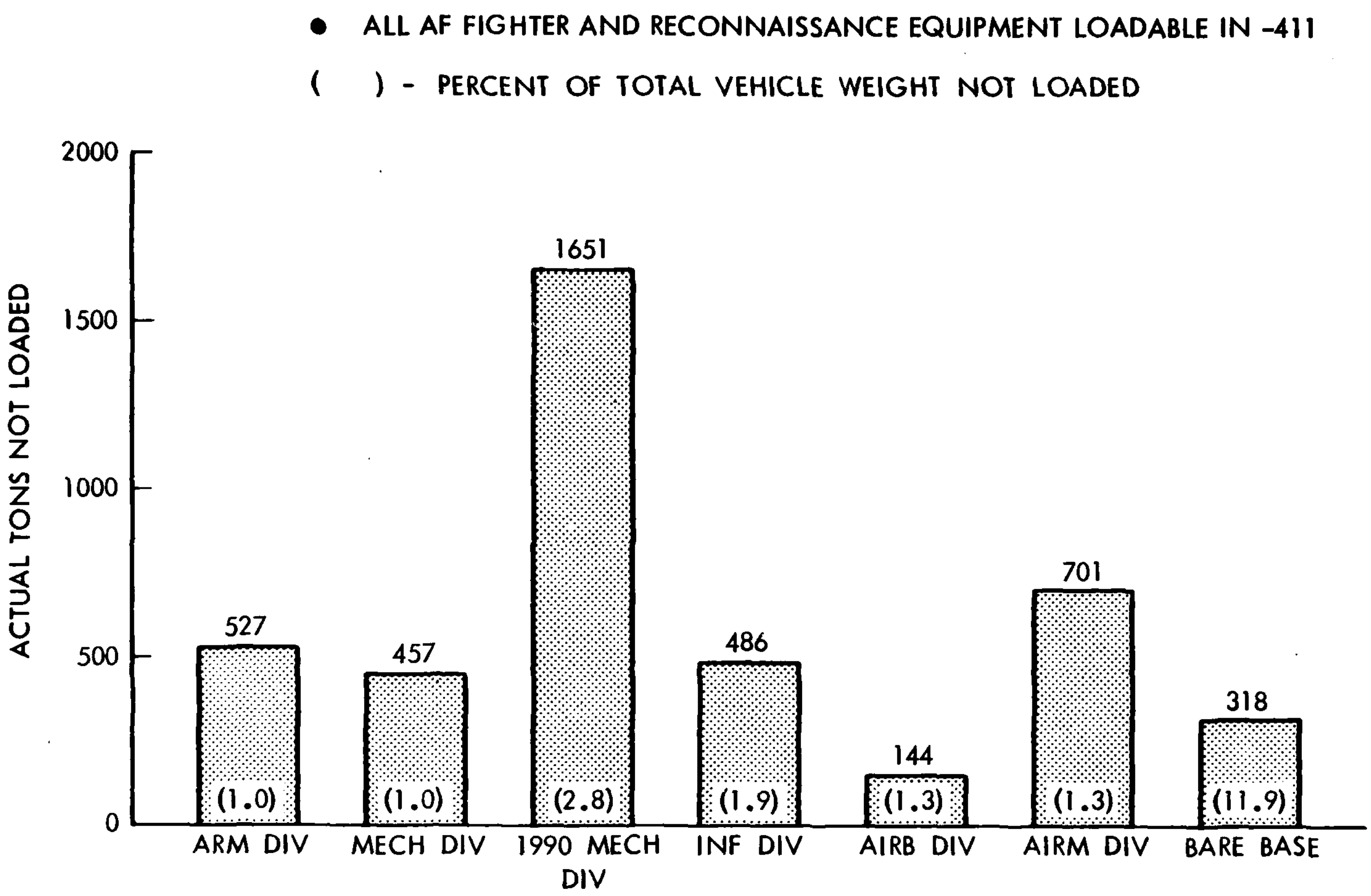
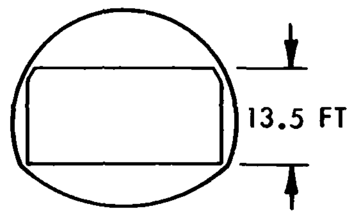
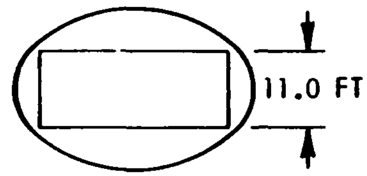


Figure 56. Flexibility Implications of 11-Foot Cargo Compartment Height

TABLE 30

REDUCED HEIGHT CARGO COMPARTMENT SUMMARY COMPARISON

MODEL NUMBER	LGA-144-400	LGA-144-411	
Fuselage Shape and Cargo Compartment Height			
MILITARY			
Payload Fraction	0.376	0.375	-0.3%
Life-Cycle Costs ($ Bil)	30.6	30.5	-0.3%
Unit Loadability (Tons)			
- Current Mech Division	50,500	50,000	-1.0%
- 1990s Mech Division	63,000	61,400	-2.8%
- AF Bare Base Unit	3,100	2,800	-11.9%
COMMERCIAL			
Fuel Economy (TNM/Gal)	22.4	22.2	-1.0%
Unit Price ($ Mil)	84.4	85.7	+1.6%
DOC (¢/ATNM)	5.61	5.65	+0.7%
DOC + ROI (¢/ATNM)	10.03	10.19	+1.5%

A description of the two resulting aircraft, the -451 and -452, is given in Table 31 along with the comparable, normally pressurized aircraft. This option reduces the gross weight of the two-radius fuselage by 5700 pounds and the four-radius oval-shaped fuselage by 7700 pounds, due to lower structural weights and air-conditioning system weights.

However, the decreased cabin pressurization reduces the flexibility of the ACMA. For commercial operations, this option means that cargoes must be segregated, since about 20 percent must be carried on pressurized aircraft. The implications for the military are shown on Table 32. Since troops can no longer be carried in the cargo compartment, the number of all-passenger sorties flown by CRAF passenger aircraft, in either the NATO or Persian Gulf scenarios, increases by 9.3 percent.

Thus, the summary comparison of Table 33 shows that decreasing the pressurization requirement increases payload fraction and decreases life-cycle costs for the military, but increases the total number of sorties required to support a NATO contingency by 9.2 percent. For the commercial operator, reducing cargo compartment pressurization lowers the direct operating costs by about one percent for the two-radius fuselage at the price of increasing cargo handling expense to segregate cargoes requiring pressurization. Note, also, that even with reduced cargo compartment pressurization, the commercial operator prefers the outsize-capable aircraft, the -451, to the oval shaped, non-outsize-capable fuselage.

MAXIMUM STRUCTURAL PAYLOAD

This design feature examines the implications of increasing the structural capability of the aircraft to allow trading fuel for additional payload for shorter than design range missions. The -400 baseline is designed to carry a 390,000-pound payload 4000 nm. The -431 option essentially "backs-up" the payload range curve to 3500 nm, as shown in Figure 57 to a payload of 416,000 pounds. Similarly, the -432 can carry 471,400 pounds for 2500 nm. Of course, both the -431 and -432 can still perform the 390,000-pound, 4000-nautical-mile mission, albeit less efficiently than the -400, as will be shown.

TABLE 31

EFFECTS OF CARGO COMPARTMENT PRESSURIZATION

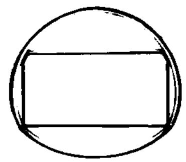
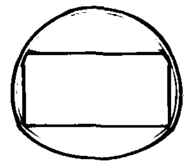
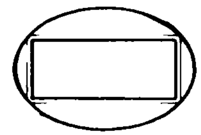
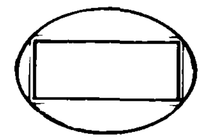
LGA-144	-400	-451	-411	-452
FUSELAGE SHAPE				
CARGO COMPT HT-FT	13.5	13.5	11.0	11.0
CABIN ALTITUDE AT 40,000 FT FLIGHT ALT	8,000 FT	18,000 FT	8,000 FT	18,000 FT
FUSELAGE WT-LB	124,200	122,200	124,400	121,200
AMPR WT-LB	319,600	315,500	319,700	314,000
BLOCK FUEL-LB	228,700	227,600	230,600	229,200
GROSS WT-LB	1,038,600	1,032,900	1,041,000	1,033,300

TABLE 32
IMPLICATIONS OF REDUCED PRESSURIZATION

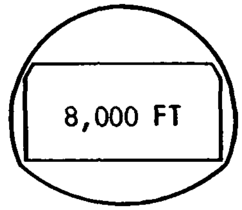
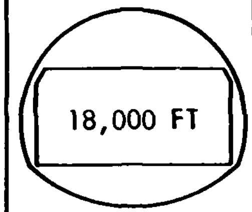
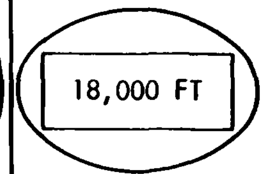
NATO SCENARIO

	-400	-451	-411	-452
NUMBER OF CARGO SORTIES	6,086	6,086	6,010	6,010
NUMBER OF TROOP SORTIES	871	1,517	881	1,517
TOTAL	6,957	7,603	6,891	7,527
	646 OR 9.3% MORE SORTIES REQUIRED		636 OR 9.2% MORE SORTIES REQUIRED	

- -411/-452 CANNOT CARRY OUTSIZED EQUIPMENT
- 747-200C USED FOR TROOP SORTIES
- PERSIAN GULF SCENARIO GIVES SIMILAR RESULTS
- COMMERCIAL IMPLICATIONS NOT EXAMINED IN DETAIL
  - ABOUT 20% OF CURRENT U.S. - INTERNATIONAL AIRFREIGHT TONNAGE REQUIRES SOME ENVIRONMENTAL CONTROL
  - EFFECT OF 18,000 FT CABIN ALTITUDE UNCERTAIN

TABLE 33

CARGO COMPARTMENT PRESSURIZATION SUMMARY COMPARISON

MODEL NUMBER	LGA-144-400	LGA-144-451	LGA-144-452
Fuselage Shape and Cabin Altitude at 40,000 ft. Flight Altitude	 8,000 FT	 18,000 FT	 18,000 FT
MILITARY			
Payload Fraction	0.376	+0.4%	+0.4%
Life-Cycle Costs ($ Bil)	30.6	-1.1%	-2.0%
Total Sorties Required for NATO Deployment	6,957	+9.3%	+9.2%*
COMMERCIAL			
Fuel Economy (TNM/Gal)	22.4	+0.5%	-0.1%
Unit Price ($ Mil)	84.4	-0.9%	-1.2%
DOC (¢/ATNM)	5.61	-0.9%	-0.4%
DOC + ROI (¢/ATNM)	10.03	-1.5%	-1.2%

*Relative to LGA-144-411

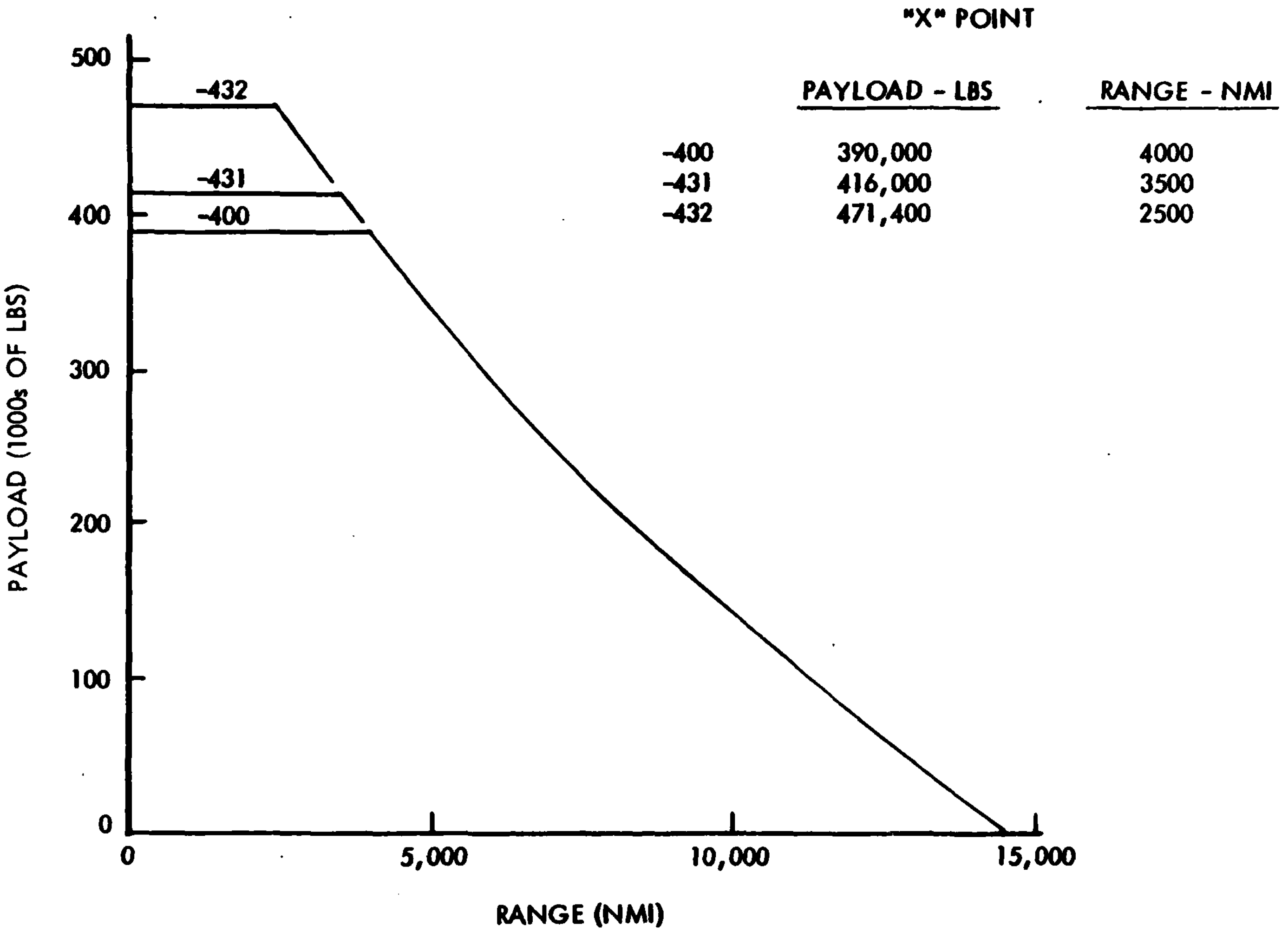


Figure 57. Payload-Range Curves for Maximum Structural Payload Design Features

When optimized, the -431 and -432 have the characteristics described in Table 34; gross weight is higher, and payload fraction and fuel efficiency are lower. But, is this additional capability worth the cost to ACMA operators?

The military benefits in cost-effectiveness are shown in Figure 58. The -431 and -432 were analyzed for their performance in both the NATO and Persian Gulf scenarios. The results show there is a benefit in cost-effectiveness for increased maximum structural payload in the NATO scenario, but apparently none in the Persian Gulf because of the longer stage lengths required.

The commercial usefulness of these options lies in the range of payload densities expected for the air freight market in 1995 and beyond. If this range lies around 8.5 to 11.5 pounds per cubic foot, then these options offer little commercial potential as depicted in Figure 59. But, if higher densities on the order of 9 to 12.2 pounds per cubic foot can be foreseen, the -431 offers lower DOCs. If payloads as dense as 10.2 to 13.8 pounds per cubic foot are the norm, then the -432 offers considerable savings to the commercial operator.

The summary comparison of Table 35 recaps these results. For a 1.2 percent higher life-cycle cost, the military obtains with the -431 a 2.3 percent improvement in NATO effectiveness, or a 1.5 percent improvement in cost-effectiveness. The commercial operator obtains benefits only if higher payload densities are anticipated for the future air cargo market.

SERVICE LIFE SPECIFICATION

This design feature deals with the differences between military and commercial operations in flight profiles and utilization rates. The -400 baseline was designed to a 30,000-hour life flying military profiles, while the -441 option considered an aircraft flying commercial profiles for 60,000 flight hours. Details of these flight profiles are given in Appendix F.

After being optimized, the -441 has the characteristics described in Table 36. Based on the assumed flight profiles, the commercial missions are slightly more damaging in terms of fatigue than the military. Thus the one

TABLE 34

EFFECT OF MAXIMUM STRUCTURAL PAYLOAD

	-400	-431	-432
MAXIMUM STRUCTURAL PAYLOAD - LBS	390,000	416,000	471,400
ALL COMPARISONS BELOW FOR A 390,000 LB PAYLOAD, 4,000 N MI RANGE MISSION			
THRUST / ENGINE - LBS	57,000	57,300	58,000
OPERATING WT - LBS	399,700	404,900	415,200
MISSION FUEL - LBS	248,500	249,900	252,600
GROSS WEIGHT - LBS	1,038,000	1,045,000	1,058,000
PAYLOAD FRACTION	.376	.373	.369
FUEL / PAYLOAD	.637	.641	.648
AMPR WT / PAYLOAD	.835	.846	.869

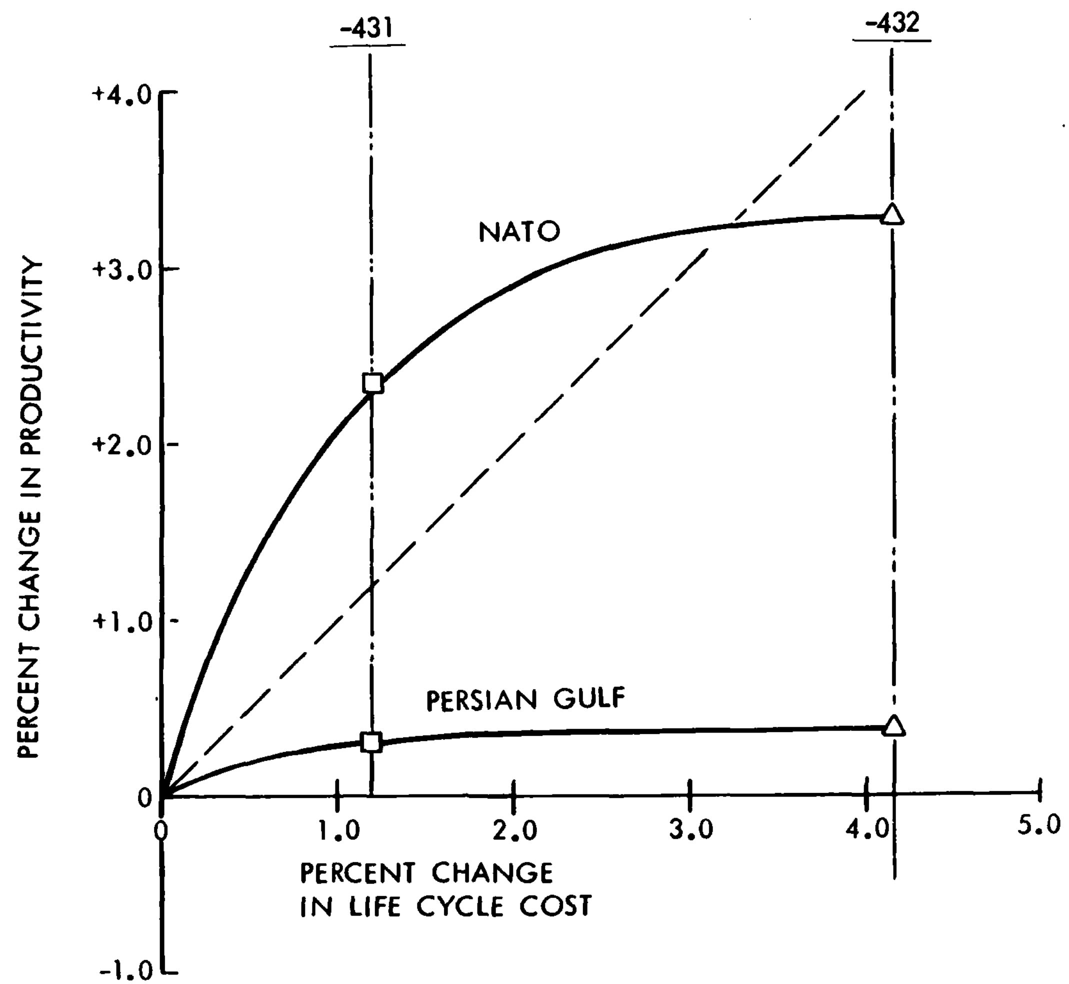


Figure 58. Cost-Effectiveness Implications of Maximum Structural Payload

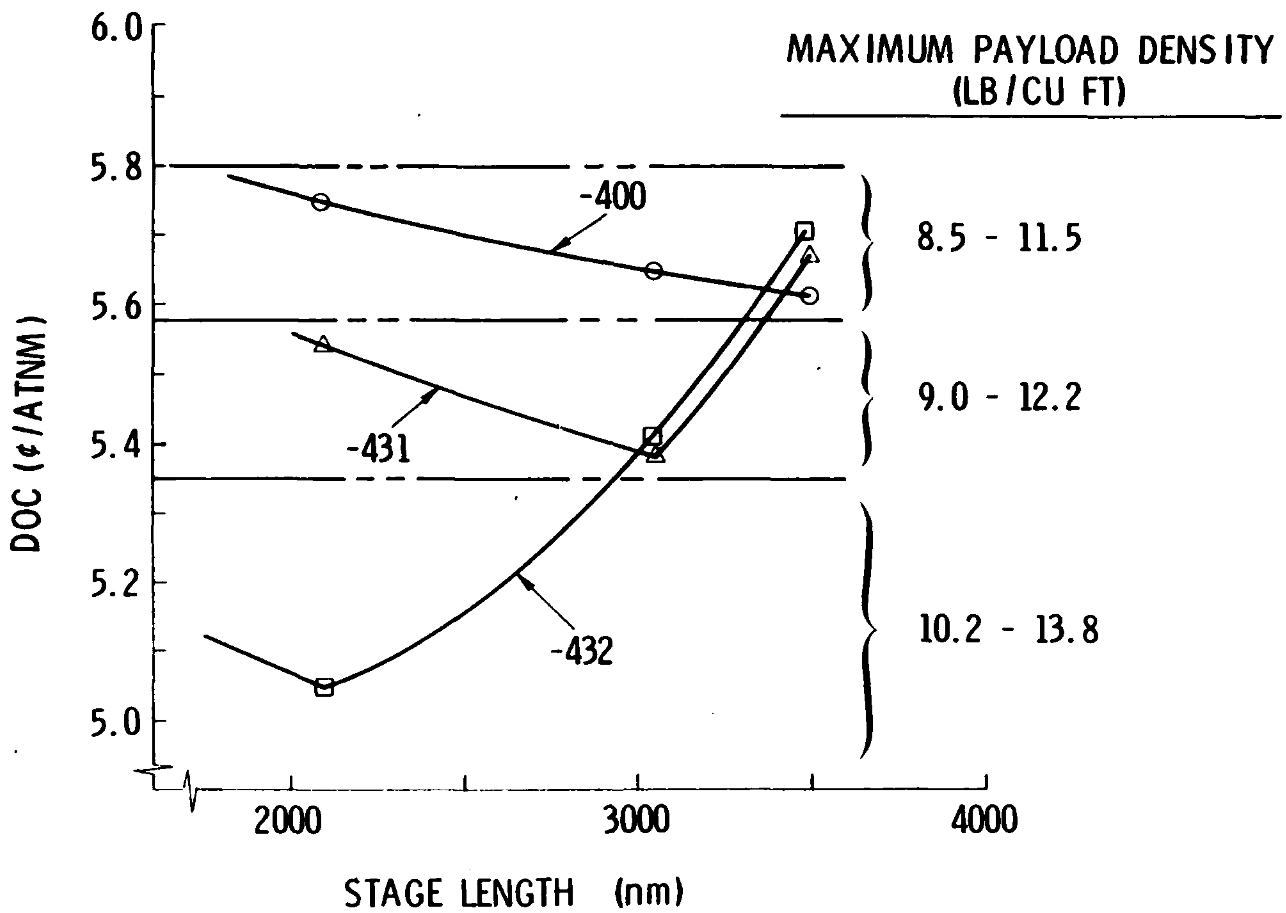


Figure 59. DOC Implications of Maximum Structural Payload

TABLE 35

MAXIMUM STRUCTURAL PAYLOAD SUMMARY COMPARISON

MODEL NUMBER	LGA-144-400	LGA-144-431	LGA-144-432
Maximum Structural Payload (Lb)	390,000	416,000	471,400
Corresponding Range (NM)	4,000	3,500	2,500
MILITARY			
Payload Fraction (at 4,000 NM)	0.376	-0.7%	-1.9%
Life-Cycle Costs ($ Bil)	30.6	+1.2%	+4.1%
NATO Effectiveness (Tons/Day)	22,500	+2.3%	+3.0%
Cost-Effectiveness ($ Mil/Tons/Day)	1.36	-1.5%	+1.1%
COMMERCIAL			
DOC-3500 NM (¢/ATNM)	5.61	+1.1%	+1.8%
DOC-3050 NM (¢/ATNM)	5.65	-4.8%	-4.3%
DOC-2100 NM (¢/ATNM)	5.74	-3.5%	-12.0%
Maximum Payload Density Range (Lb/Cu Ft)	8.5 - 11.5	9.0 - 12.2	10.2 - 13.8

TABLE 36
EFFECT OF SERVICE LIFE SPECIFICATION

PARAMETER	-400	-441	% CHANGE
DESIGN CHARACTERISTICS			
- SERVICE LIFE-HRS	30,000	60,000	-
- MISSION PROFILE	MILITARY	COM'L	-
ALTERNATE CAPABILITY			
- SERVICE LIFE-HRS	28,600	62,300	-
- MISSION PROFILE	COM'L	MILITARY	-
FIGURES OF MERIT			
- OPERATING WEIGHT-LBS	394,800	401,800	1.8
- BLOCK FUEL-LBS	228,700	231,400	1.2
- GROSS WEIGHT-LBS	1,038,600	1,048,500	1.0
- PAYLOAD FRACTION	0.376	0.372	-1.1

percent higher gross weight of the -441 is largely due to the longer expected lifetime of that aircraft. The summary comparison in Table 37 shows that NATO effectiveness is not changed by this specification, but life-cycle costs are increased almost one percent. The commercial operator pays 2.5 percent more for the aircraft initially but obtains considerable operating cost reductions due to the longer aircraft lifetime over which the depreciation can be written off.

PASSENGER PROVISIONS

The final Group IV design feature deals with various options for the carriage of passengers. The -400 baseline has no provisions except for fold-down C-141-type bench seats in the cheeks of the cross section. Also, C-5-type seat and comfort pallets could be installed for troop movements. The four options to the baseline have provisions which would be suitable for commercial passenger operations. A primary impetus of this kind of consideration is supplied by the trends shown in Figure 60. The price-elasticity of demand for air travel is reflected in the growth in revenue passenger miles since the onset of discount fares.

An ACMA type aircraft in commercial service might have considerable appeal as a combi, especially when the -400 baseline inboard profile is examined. In Figure 61, note that aft of the wing box and above the cargo compartment there exists a tremendous volume that is not being utilized. For the -421, an integral passenger compartment is installed in this space without intruding into the 13.5-foot height of the cargo compartment. This arrangement results in a 9-seat abreast row with a ceiling height at the aisles of 76 inches. For the -422, the floor of the passenger compartment is lowered such that the cargo compartment height is 11.5 feet, high enough for commercial containers and most military vehicles. This arrangement features a 10-abreast row with a ceiling height at the aisles of 84 inches and space for overhead stowage of carry-on luggage. The -423 is similar to -400 except that provisions are made to carry two-deck passenger modules. Finally, the -424 combines the integral compartment of the -422 with provisions for single deck modules. Typical cross sections for these options are shown in Figure 62.

TABLE 37

SERVICE LIFE SPECIFICATION SUMMARY COMPARISON

MODEL NUMBER	LGA-144-400	LGA-144-441	% CHANGE
Service Life Specification (Hrs)	30,000	60,000	+ 100
Mission Profile Type	Military	Commercial	-
MILITARY			
Payload Fraction	0.376	0.372	-1.1
NATO Effectiveness (Tons/Day)	22,500	22,500	0.0
Life Cycle Costs ($ Bil)	30.6	30.8	+0.9
COMMERCIAL			
Fuel Economy (TNM/Gal)	22.4	22.1	-1.7
Unit Price ($ Mil)	84.4	86.5	+2.5
Expected Service Life (Yrs)	7.8	16.4	+110
DOC (¢/ATNM)*	7.90	5.99	-24.2
DOC + ROI (¢/ATNM)*	12.32	10.50	-14.8

*Depreciated over expected life to zero residual

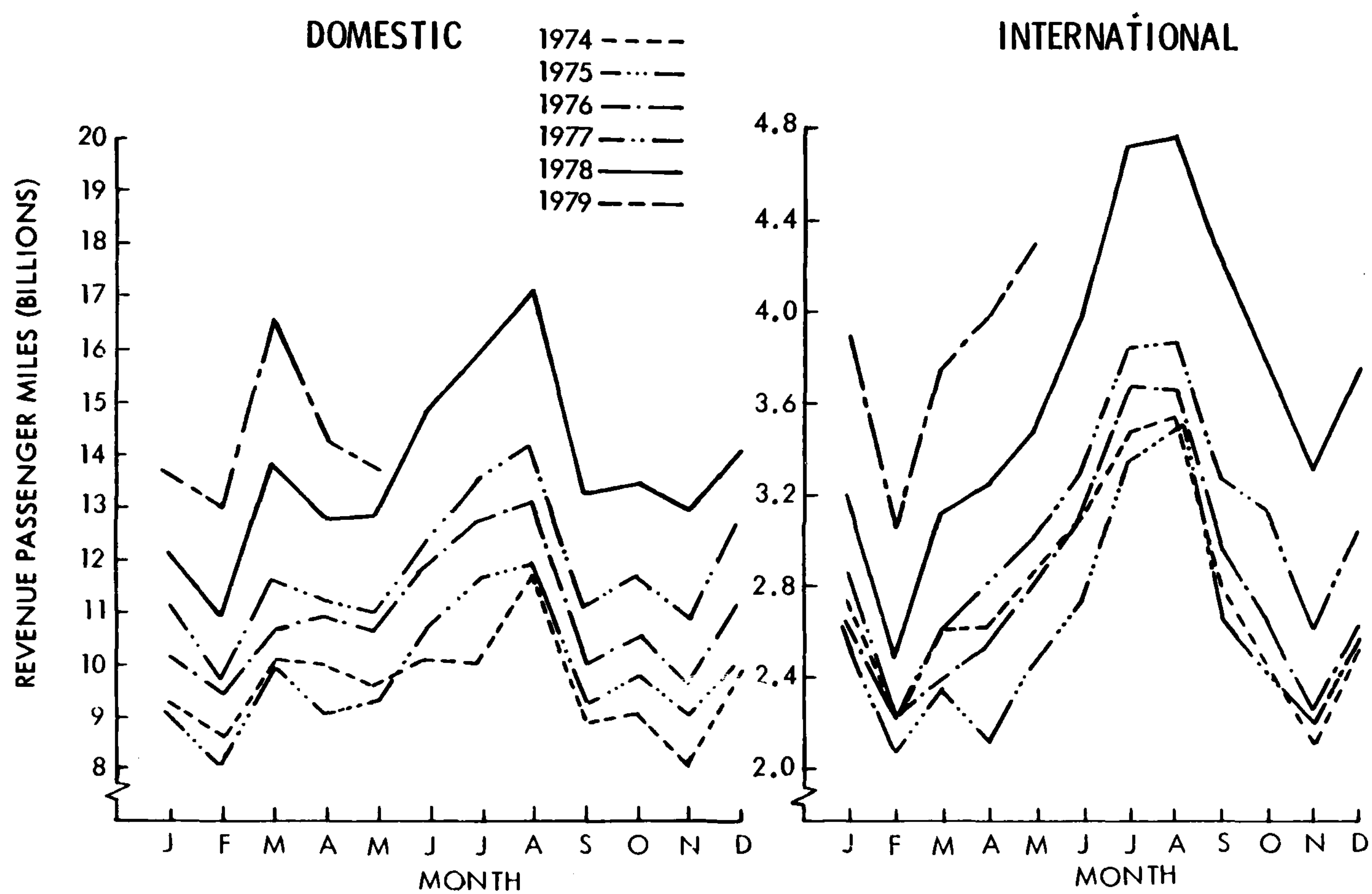


Figure 60. Passenger Traffic Trends

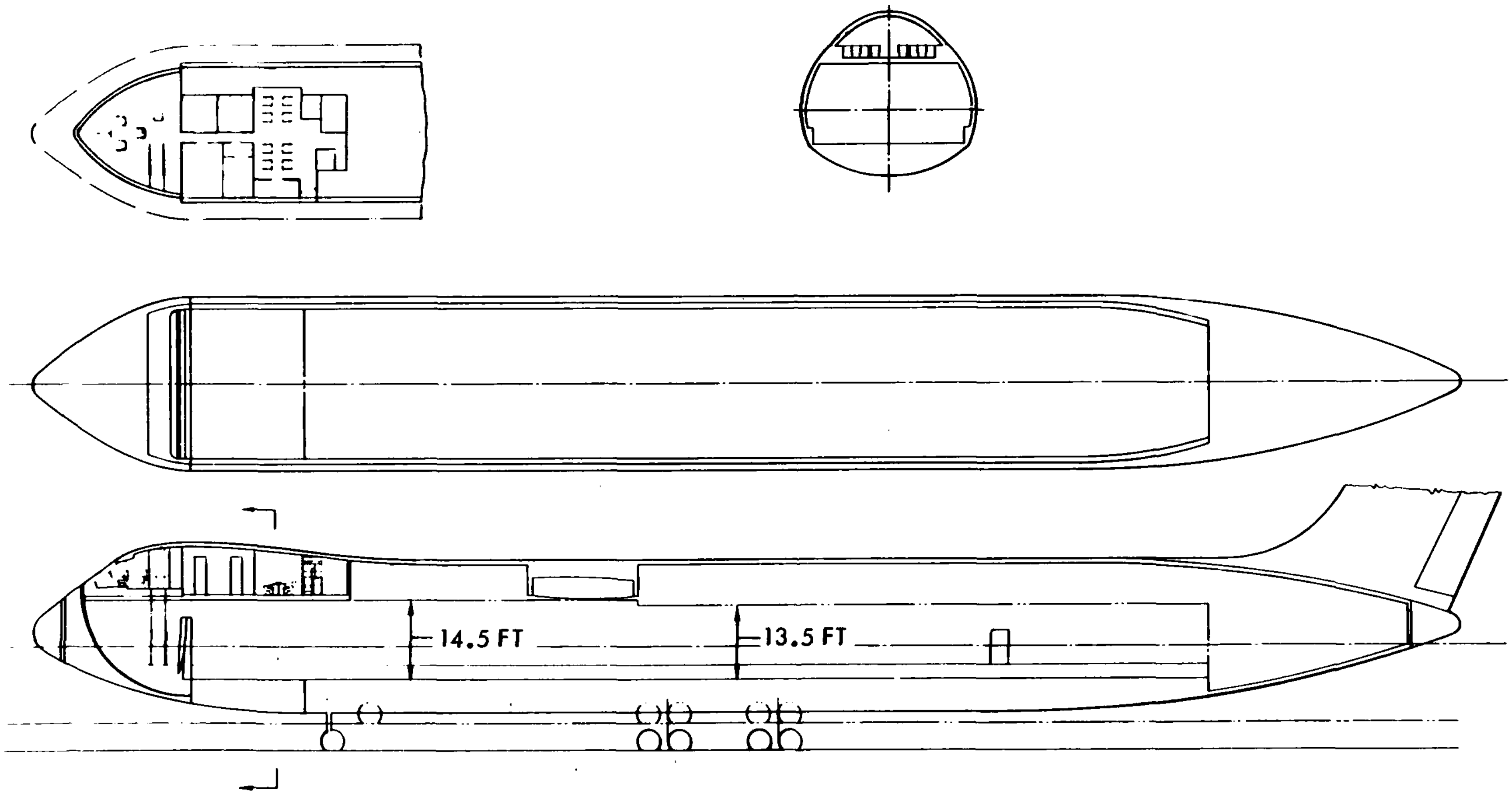


Figure 61. Inboard Profile: LGA-144-400

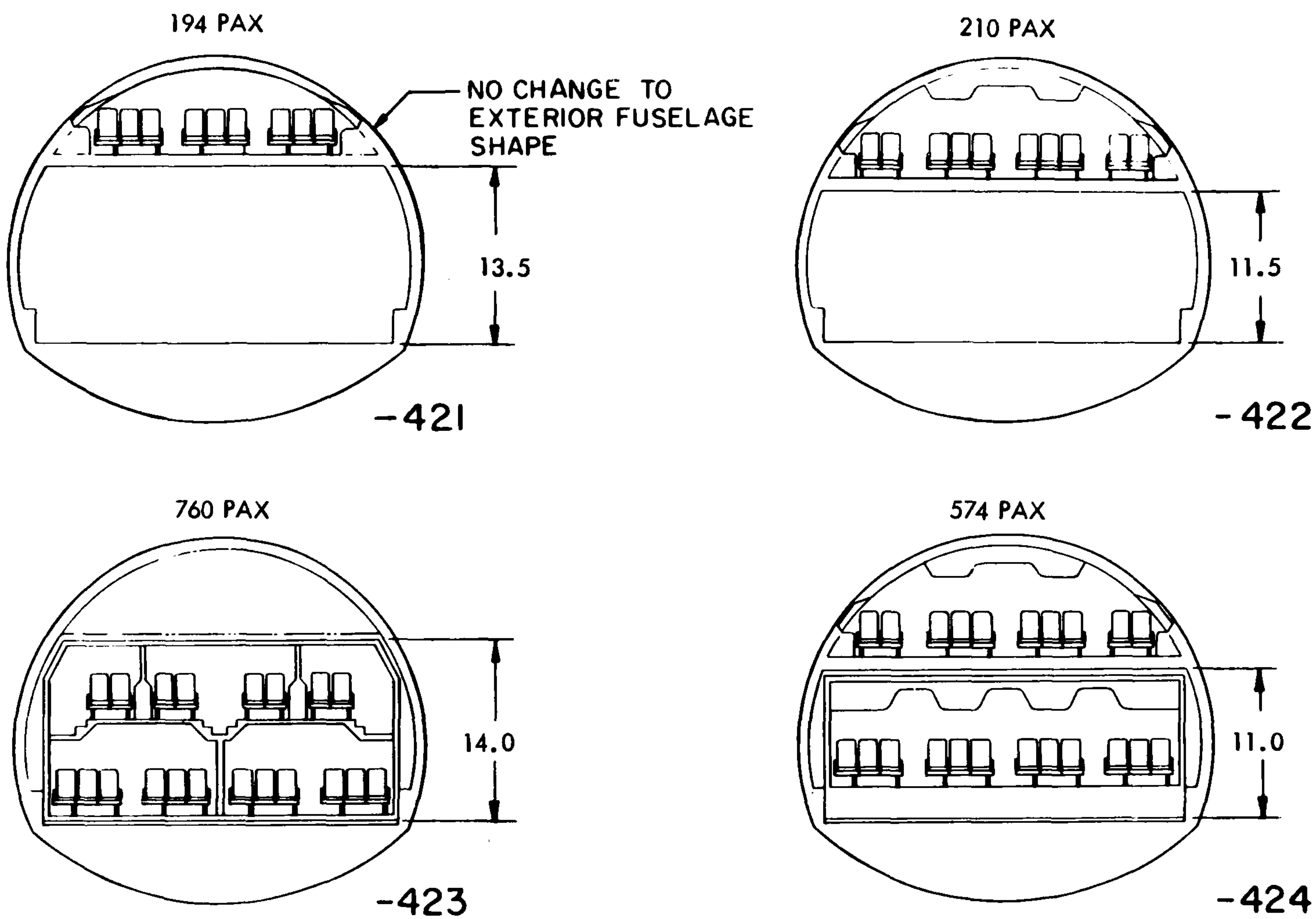


Figure 62. Passenger Option Cross Sections

In the case of integral compartments, design payload is increased to allow for the passengers and their baggage. For the aircraft with modular capability, however, the baseline design payload is used for the module structure and furnishings, the passengers, and their luggage.

The integral compartment changes the external appearance of the aircraft only slightly, as can be seen in Figure 63. The -422 is shown to illustrate the inclusion of doors, windows, and over-the-wing escape hatches. An inboard profile of this aircraft, Figure 64, dramatically displays the changes to the inside necessary for commercial passenger operations. The passenger compartment contains 210 tourist-class seats which are serviced by seven lavatories and a below-decks galley in the aftbody.

The passenger modules shown on Figure 65, were designed to be 20 feet long and 27 feet wide. The -423 uses 14-foot high modules, which are tall enough for two decks. Doors must be provided in both the modules and the sides of the aircraft itself for emergency evacuation. Doors are also provided at the front and rear of each module which can be opened for fore and aft passenger movement. The 11.0-foot high modules of the -424 contain only one deck and thus have considerable volume under the floor that cannot be utilized. Special purpose modules (not shown) are required for galleys and toilets.

The optimized point design aircraft incorporating each of these four options are compared in Table 38. The increase in payload has already been explained. Operating weight is increased by extra structure and furnishings in the passenger cabins for the -421, -422, -424, and for the provisions for modules on the -423 and -424. Thus the gross weight increases considerably for these passenger configurations.

There is much work to be done to properly analyze commercial passenger provisions as part of the ACMA system concept. The following discussion focuses on four ways of making commercial economic comparisons:

1. All cargo configurations.

2. All-passenger configurations (-423 and -424 only).

CRUISE MACH NO.	0.78
DESIGN PAYLOAD	431,000 LB
DESIGN RANGE	4,000 NM
OPERATING WT.	460,700 LB
MAX. GROSS WT.	1,175,200 LB
ASPECT RATIO	10.1
WING LOADING	129.4 PSF
THRUST PER ENGINE	65,700 LB

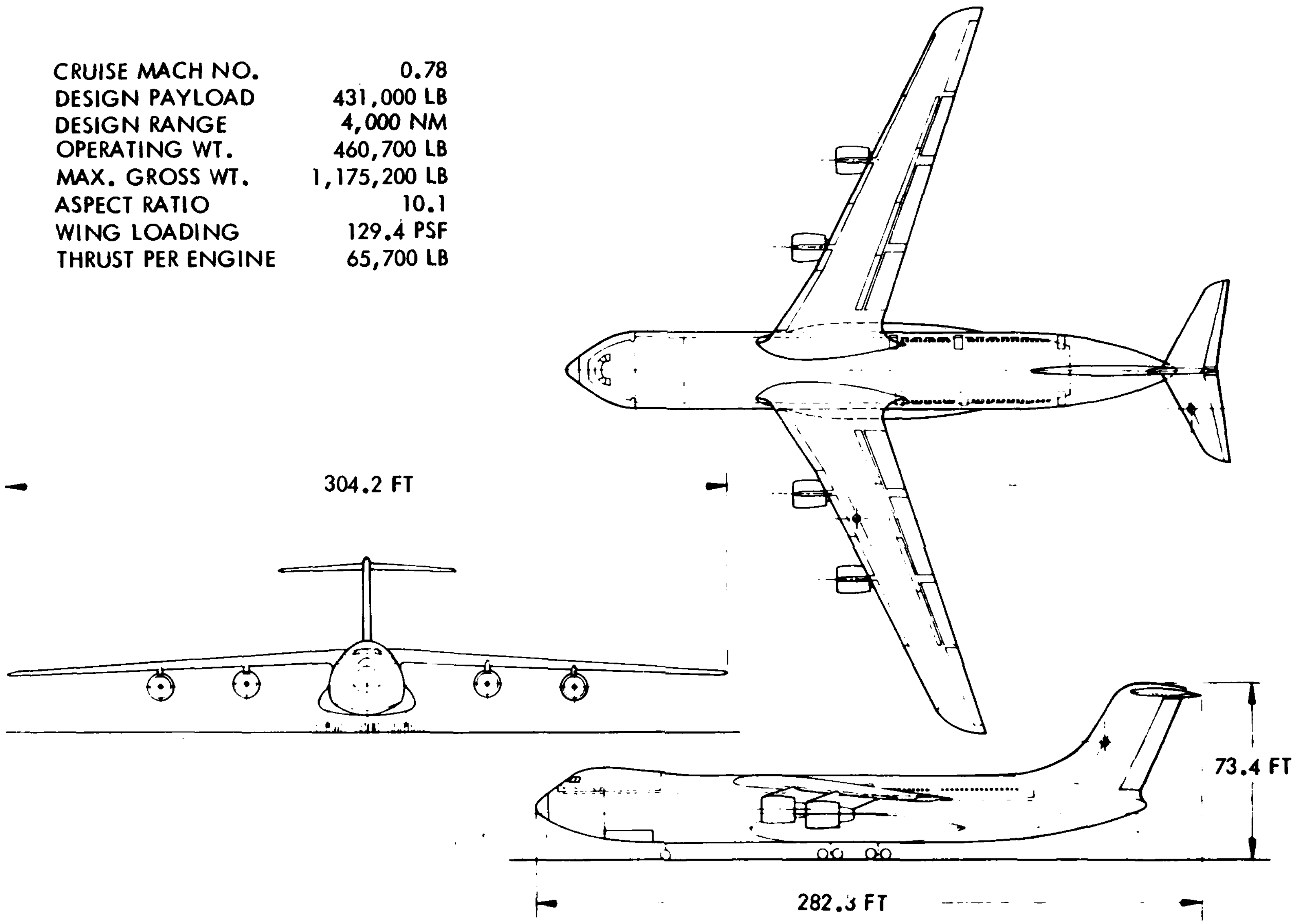


Figure 63. General Arrangement: LGA-144-422

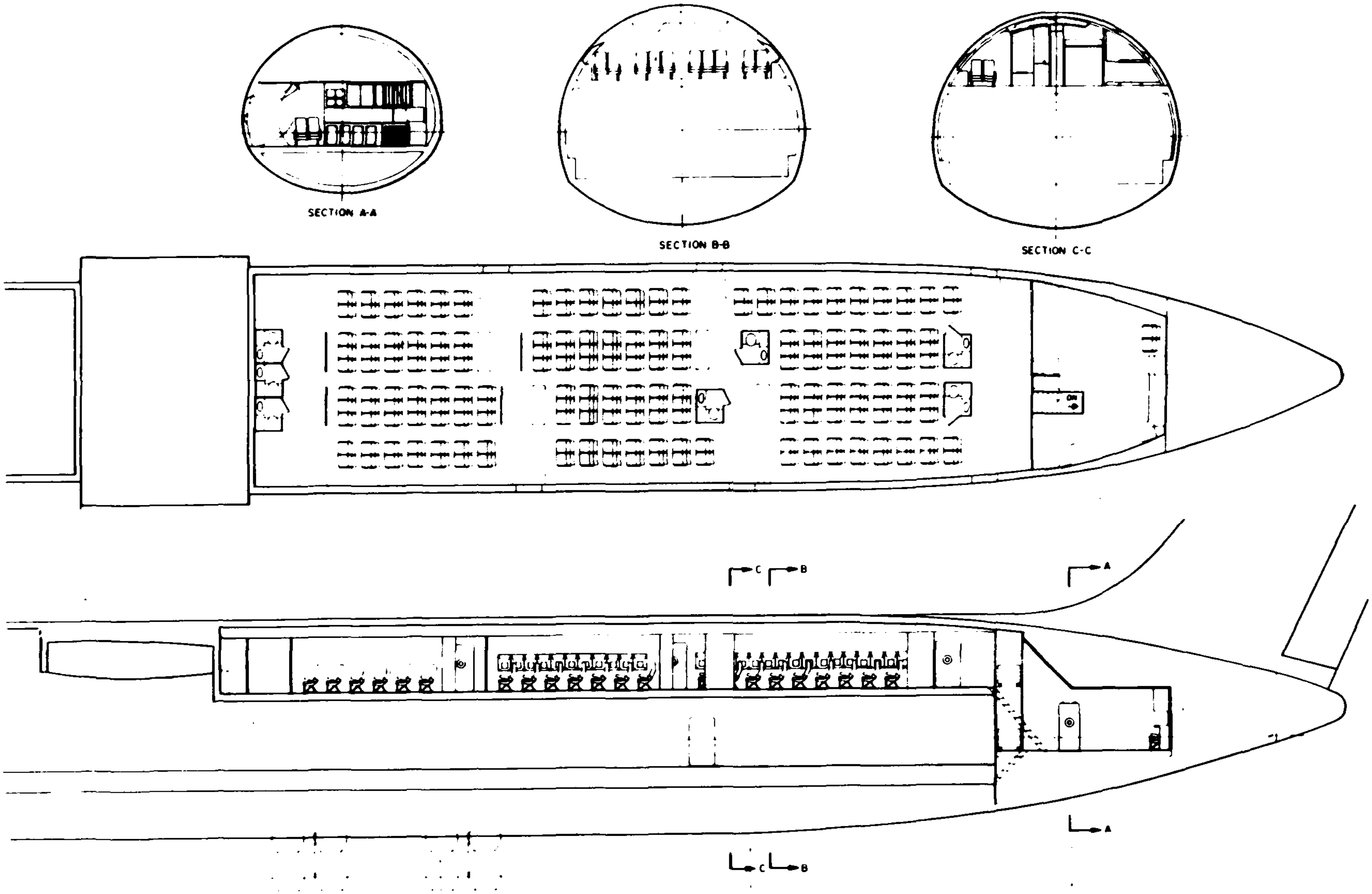


Figure 64. Inboard Profile: LGA-144-422

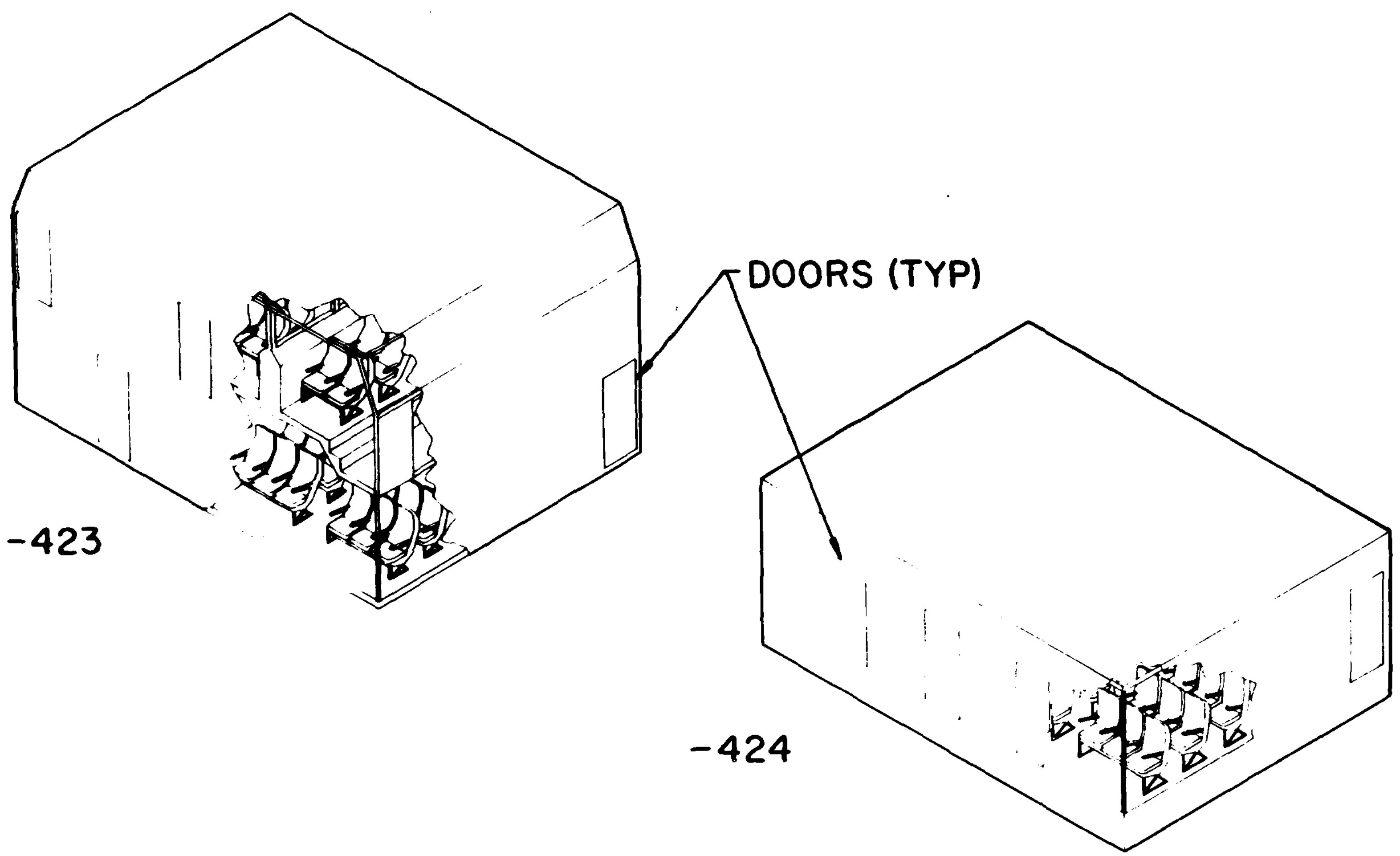


Figure 65. Module Configurations

TABLE 38

COMPARISON OF PASSENGER CONFIGURATIONS

	-400	-421	-422	-423	-424
● TYPE OF PASSENGER ACCOMMODATIONS	BENCH-SEATS IN CHEEKS	194 SEATS IN INTEGRAL COMP'T	210 SEATS IN INTEGRAL COMPT'T	760 SEATS IN MODULES	210 SEATS IN INTEGRAL COMP'T + 364 SEATS IN MODULES
● AIRCRAFT CHARACTERISTICS					
PAYLOAD - LBS	390,000	427,900	431,000	390,000	431,000
OPERATING WT - LBS	394,800	454,300	460,700	454,500	488,600
GROSS WT - LBS	1,038,600	1,163,600	1,175,200	1,114,900	1,211,300
ENGINE THRUST - LBS	58,300	65,100	65,700	62,400	67,800
BLOCK FUEL - LBS	228,700	253,400	255,500	243,600	262,800

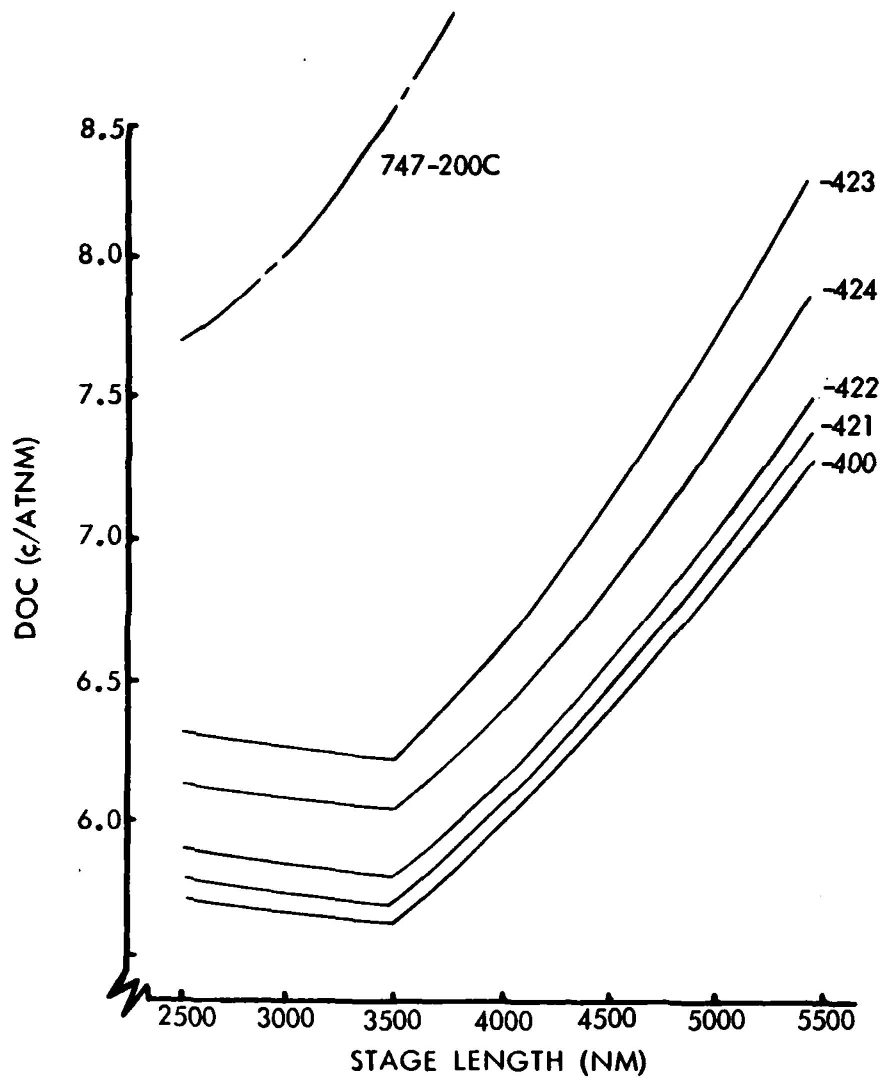
3. Combi passenger/cargo configurations with a focus on cargo costs.

4. Combi passenger/cargo configurations with a focus on passenger costs.

Figure 66 presents the all-cargo configuration comparison. Here, none of the aircraft are carrying passengers; the entire payload is carried as cargo on the main deck, resulting in higher payload densities for the -421, -422, and -424. The extra structure and furnishings cause all of the new aircraft to fare poorer than the -400, but the aircraft with integral accommodations represent significantly smaller penalties compared to the baseline than those with modular capability.

The all-passenger comparison of Figure 67 features only the two module-carrying aircraft, the -423 and -424, and compares them to a 747-200C configured for all-tourist seating. The -423 and -424 are at their maximum module capacity of 760 and 364 passengers, respectively, and the -424 also carries the 210 passengers in the integral compartment. Although this is a considerable under-gross-weight condition, credit is not taken for the reduced fuel consumption in this comparison. It shows that the module-carrying aircraft are not efficient all-passenger configurations compared to the 747, not an unexpected result when the redundant structure, wasted cross-section space, and military vehicular capability of the -423 and -424 are considered.

The third comparison of commercial economics, shown in Figure 68, is one where, of the total trip cost for each aircraft, an increment representing passenger costs based on 747-200C DOCs is subtracted out, with the remaining costs charged to the main deck cargo. The -423 has a comfort module and one passenger module in the two aft-most rows of the cargo compartment. Thus, these point designs offer cargo DOC's in combi operations of about one-half that of the 747. Finally, Figure 69 shows another way of looking at combi operations: cargo costs based on -400 DOCs are subtracted out of trip costs, with the remaining costs charged to the passengers. This comparison shows that costs per seat mile for carrying passengers to be even less than half those of the 747.



MODEL	MAX PAYLOAD (TONS)
-400	202.1
-421	221.1
-422	222.7
-423	202.1
-424	222.6

Figure 66. Economic Comparison: All-Cargo Configurations

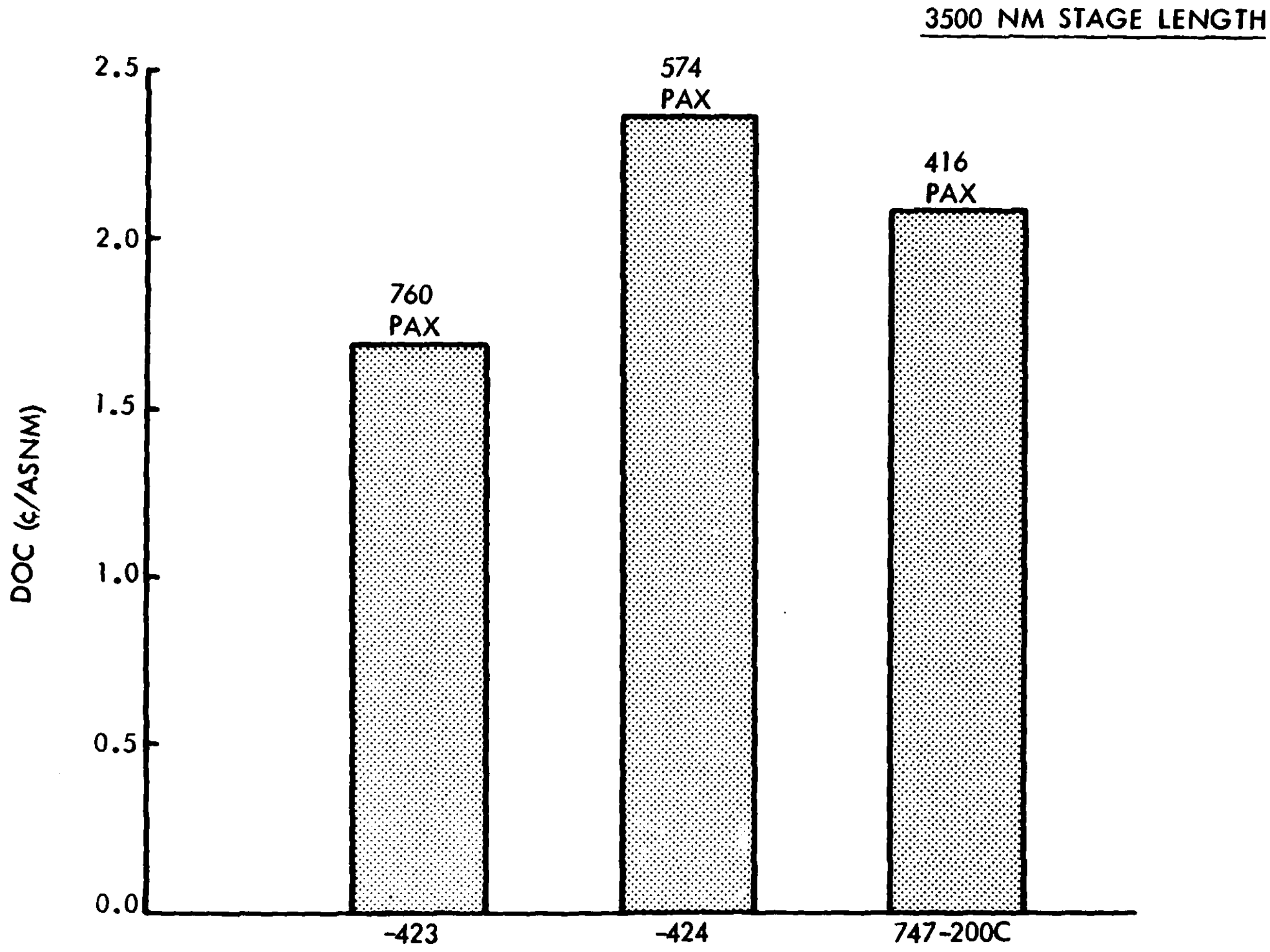


Figure 67. Economic Comparison: All-Passenger Configurations

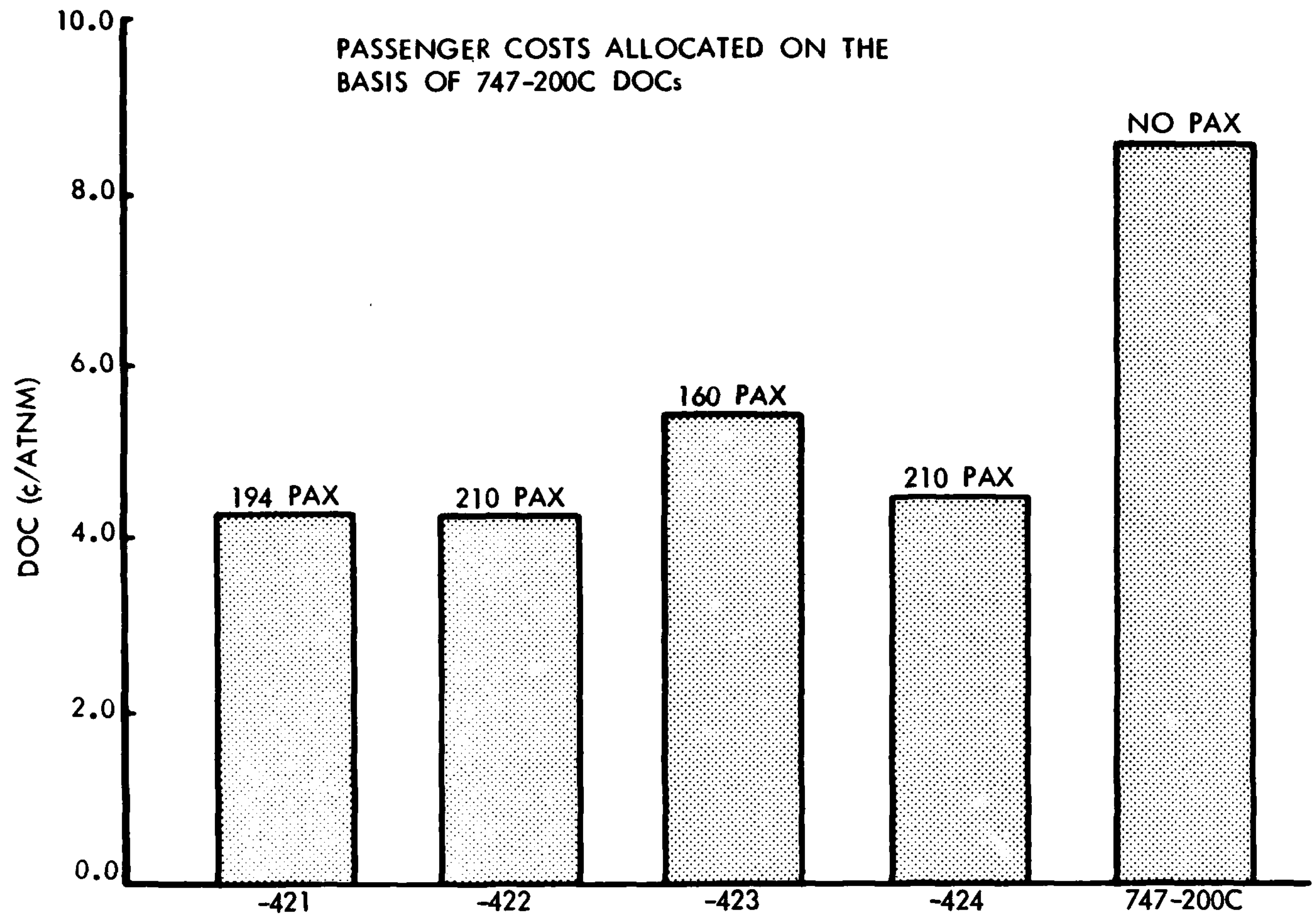


Figure 68. Economic Comparison: Combi Cargo DOCs

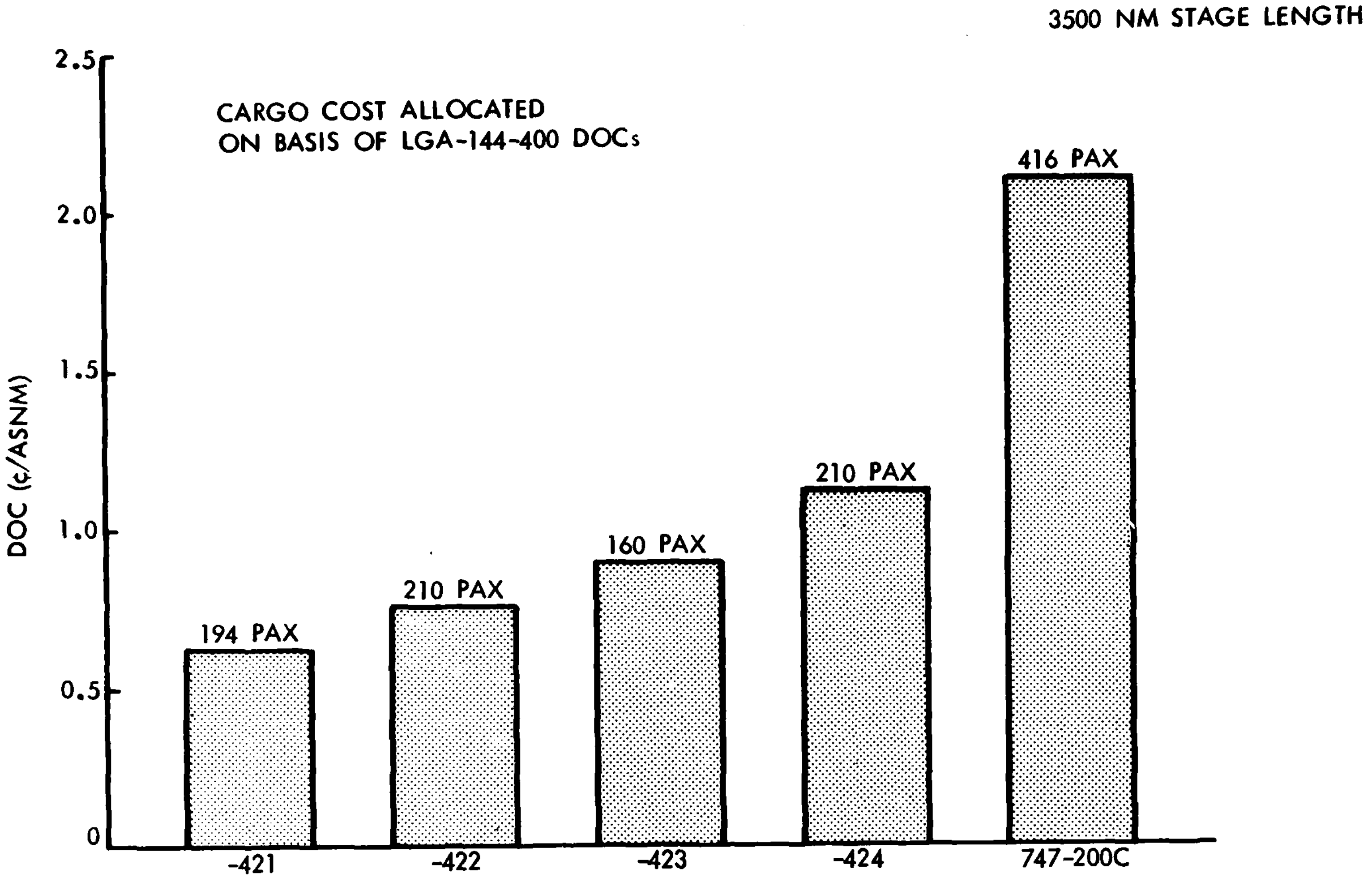
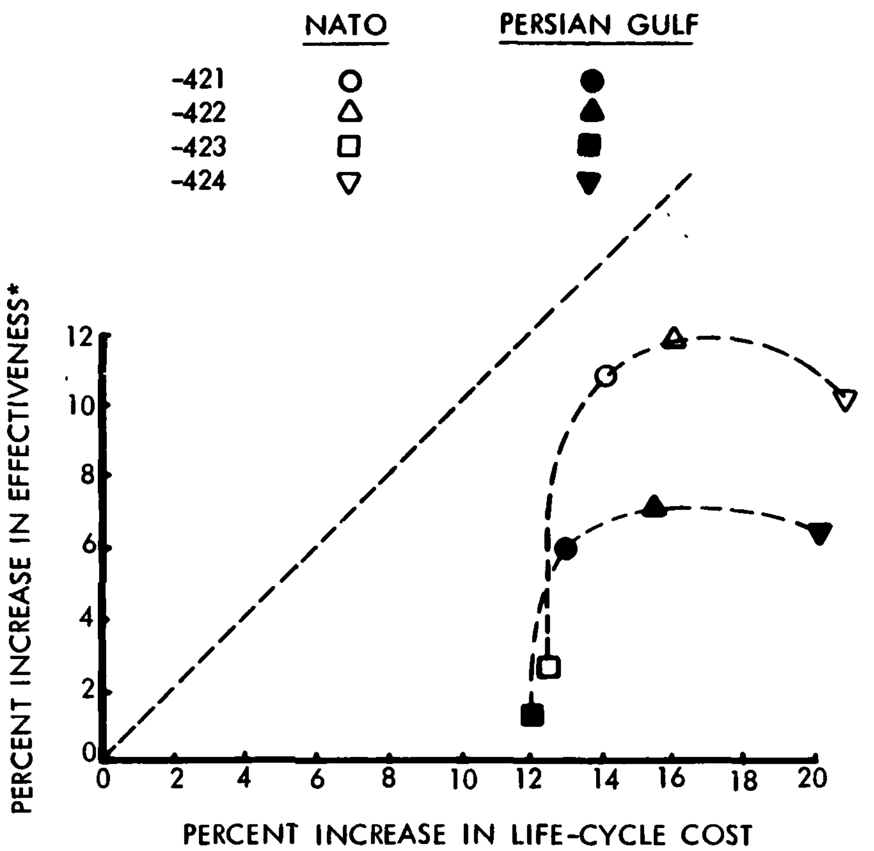


Figure 69. Economic Comparison: Combi Passenger DOCs

For the military, however, passenger operations do not appear quite so attractive. Figure 70 is the result of an analysis of both the NATO and Persian Gulf scenarios where the four point design aircraft are used to airlift all cargo and troops. It shows that none of the options offers effectiveness benefits commensurate with the increased life-cycle costs, although no benefit is taken for the increased troop comfort compared to riding in the cargo compartment on seat pallets.

To summarize the passenger provisions design feature, Table 39 compares the -400 baseline with the -422, which has an integral compartment, and with the -424, which has the integral compartment and provisions for passenger modules. For the military, special passenger provisions do not appear cost effective, although integral provisions are more attractive than modular. Commercially, the all-passenger configurations using modules are not particularly attractive. However, the integral accommodations appear to offer substantial revenue potential because of the very low incremental operating cost of adding passenger seats in previously unused space.



*ASSUME NO OTHER PASSENGER LIFT IS AVAILABLE

Figure 70. Military Cost-Effectiveness of Passenger Options

TABLE 39

PASSENGER PROVISIONS SUMMARY COMPARISON

MODEL NUMBER	LGA-144-400	LGA-144-422	LGA-144-424
Number of Passengers (Max)	542	752	574
Type of Accomodations:			
Bench Seats/Pallets	542	542	-
Integral Comp't.	-	210	210
Modules	-	-	364
MILITARY			
Payload Fraction	0.376	-2.7%	-5.3%
Life-Cycle Costs ($ Bil)	30.6	+14.1%	+15.7%
NATO Effectiveness (Tons/Day)	22,366	+11.4%	+10.1%
Cost-Effectiveness ($ Mil/Tons/Day)	1.368	+2.4%	+5.0%
COMMERCIAL			
Fuel Economy (TNM/Gal)	22.4	-10.7%	-13.4%
Unit Price ($ Mil)	84.4	+17.8%	+25.5%
DOC (¢ /ATNM)	5.61	-24.4%*	-20.0%*
DOC (¢ /ASNM)	2.09 (747-200C)	-63.6%**	-46.4%**

* Assuming passenger costs are allocated on the basis of 747-200C

** 210 passengers, assuming cargo cost are allocated on the basis of LGA-144-400C

VIII. CONCLUDING OBSERVATIONS

This final section summarizes the principal observations from our work on the Design Options Study. In general terms, we believe that both major study tasks—the qualitative assessment and the detailed analysis of selected design features and associated options--will be useful to Air Force decision makers as well as to potential civil operators.

Although the qualitative assessment represents significant progress in identifying the design features and options of interest to a joint transport program, much work in this area is still required. Specifically, additional inputs from a broad range of users, particularly from the commercial sector, are required to establish the ultimate credibility of the assessment. The primary motivation for broadening the base of the assessment is mainly related to the subjective nature of this type of analysis.

The detailed analyses of design options performed thus far are merely the "tip of the iceberg" of analyses of this type which must be performed before the functional specifications of the ACMA can be finalized. Nonetheless, results presented in this report will be useful for more clearly focusing on some initial system specifications. Also of importance is our having demonstrated that the implications of relatively small changes to the aircraft configuration can be successfully explored at the conceptual design level in a quantitative context.

More specific observations regarding the present effort are given in the following paragraphs. Observations related to the design aspects of a civil/military transport are presented first; these are followed by a summary of the overall viability of the ACMA commonality concept based on the work performed to date.

DESIGN ASPECTS OF A CIVIL/MILITARY TRANSPORT

Significant observations associated with the detailed analyses performed in the present effort are discussed below in terms of the four groups employed throughout this report. By way of summary, cost and effectiveness

implications of those features that appear to resist the commonality concept are also presented.

Group I

As shown in Section IV, design payload has a substantial effect on all aircraft design parameters (e.g., maximum gross weight) in absolute terms. However, only small variations are observed for most normalized figures of merit (e.g., payload fraction, life-cycle cost for equal fleet productivity, or direct operating costs). In other words, economies of scale favoring the larger aircraft tend to be dominated by production quantity effects, primarily due to the learning curve effect as well as the ability to spread the lower total development costs of smaller aircraft over a greater number of units.

Based on these considerations, a design payload between 360,000 and 390,000 pounds appears most appropriate for the ACMA. Such a design payload ensures the capability of carrying three of the Army's new main battle tanks, the XM-1. Having this capability (as opposed to being just shy of the three-tank threshold) was found to be very important. Of course, this result is strongly related to the technology level assumed for this report as well as the assumed magnitudes of both the military requirement and civil market for the ACMA aircraft.

Group II

Including a rear aperture in the ACMA results in a substantial penalty in commercial economics (about 7 percent in DOC). Interestingly, however, a rear aperture also entails a penalty in cost-effectiveness from a military viewpoint assuming, of course, that air drop capability is not a firm requirement and that absolutely minimizing ground-time for off-loading is not an overriding concern. Discounting these latter possible requirements, the penalty in military cost-effectiveness associated with retaining the rear aperture is about 4 percent.

Whether or not the forward aperture should be full width is a more subtle issue. Incorporating a full-width aperture in the aircraft entails small

penalties in both military and commercial contexts, about 4 percent and 1.5 percent respectively. However, there are obvious benefits to a full-width opening that are difficult to explicitly incorporate in classical cost-effectiveness analysis. For example, a full-width door eliminates the frustration of not being able to load an odd-sized item because it will not pass through the doors, despite the cargo-compartment being large enough to accommodate it. Militarily, full-width openings simplify the backing of articulated vehicles (i.e., any prime mover and trailer) into the aircraft; commercially, at the very least, a full-width door eliminates the complicated switching system required for the loading of containers and pallets (i.e., going from a two-stick door to a three-stick cargo compartment). To summarize, a full-width aperture assures superior loading characteristics, but entails relatively small cost penalties in both military and commercial contexts.

Finally, whether or not a kneeling landing gear should be included presents one of the few dichotomies between military and commercial interests. A more detailed discussion of the feature is presented later in the section.

Group III

The takeoff distance design feature investigation resulted in one of the happy outcomes of the present effort. Such is the case because of the differences between military and commercial takeoff distance criteria. Specifically, a design takeoff distance of 9500 ft over a 50 ft obstacle (with all engines operating) translates to a military critical field length of about 7950 ft and an FAA field length of about 10,600 ft. From the viewpoint of commonality, this situation approaches the ideal.

The desirable landing gear flotation is a much more complex--and, for the most part, very subjective--issue. Again, a detailed discussion will be given later in this section.

Achieving the FAR 36, Stage 3 noise limits appears feasible. As subsequently discussed, meeting these criteria is a necessary element of any joint aircraft program.

Group IV

Cargo-compartment maximum height and reduced cargo-compartment pressurization are features that should be considered simultaneously. With normal cargo-compartment pressurization, reducing the height of the cargo-compartment from full-outsize (i.e., maximum height at least 13.5 ft) is counterproductive, both militarily and commercially. This result is a consequence of the structural beef-up required once a single circular-arc upper-fuselage lobe is abandoned; of course, for a three-stick airplane, a single arc upper lobe provides outsize capability as a consequence of simple geometric considerations.

Coupling reduced pressurization and reduced cargo-compartment height (i.e., an oval shape made up of three circular arcs that provides a maximum cargo compartment height of 11.0 ft) can provide costs that are slightly less (about 0.4 percent in direct operating cost) than those associated with the normal-pressurization, fully outsize-capable aircraft. However, the loss of military and commercial flexibility associated with such an arrangement would probably far outweigh this slight cost advantage.

Increasing the maximum structural payload beyond the design payload (i.e., trading fuel for payload at stage lengths less than the design range) may be an attractive option. From a military viewpoint, the increased payload yields improved cost-effectiveness in the NATO scenario at the expense of poorer cost-effectiveness in the Persian Gulf scenario. Commercially, the attractiveness of increased structural payload is largely dependent on whether or not net payload densities greater than about 11 lb per cu ft can be profitably exploited.

Perhaps the most complex feature examined in the present effort is that of providing passenger accommodations in the ACMA. Once again, however, discussion of this feature will be presented subsequently.

SUMMARY: DESIGN FEATURES RESISTING COMMONALITY

Table 40 summarizes the design features that, based on the current effort, tend to resist civil/military commonality. These are divided into two categories: "Definite Hindrances" to commonality, in which military and commercial interests conflict, and "Possible Hindrances," in which the difference between what is desirable militarily and commercially is not so readily apparent.

Most prominent in the definite hindrance category is the cargo-compartment floor height. In our work, this feature translates to whether or not the ACMA should incorporate a kneeling landing gear. (As discussed in Volume III, it is almost a certainty that a high-wing configuration is most appropriate for a cargo airplane.) Table 40 indicates that the penalty in DOC associated with incorporating a kneeling capability is 2.6 percent. On the other hand, if the kneeling feature is not incorporated, a penalty of over 6 percent in military cost-effectiveness is borne.

The elimination of the preceding dilemma may be straightforward. Organic military aircraft would incorporate the kneeling landing gear. Commercial aircraft would not have the kneeling capability; when activated in a CRAF mobilization, the longer required ramp extensions would be installed. Such a strategy maintains the viability of the commonality concept while imposing only modest penalties in the military usefulness of the commercial aircraft.

The second and third features in the first category shown in Table 40 reflect a distinctly different situation. In these cases, achieving the FAR 36, Stage 3 noise regulations, the commercial engine-out climb gradient, and providing at least a 60,000-hour commercial service life are, in our view, essential if the ACMA is to be a commercial success. (Hence, the N/A—Not Applicable—notation for quantifying the civil penalty.) In these instances, the penalties in cost-effectiveness must be accepted by the military as a necessary compromise which appears unavoidable if commonality is to be achieved.

TABLE 40

DESIGN FEATURES RESISTING CIVIL/MILITARY COMMONALITY

DESIGN FEATURE	% PENALTY CIVIL*	% PENALTY MILITARY**
● DEFINITE HINDRANCES		
- Cargo-Compartment Floor Height	2.6	6.1
- Noise Characteristics / Climb Gradient	N/A	2.5
- Service-Life Specification	N/A	0.9
● POSSIBLE HINDRANCES		
- Landing Gear Flotation	1.8	O/C
- Passenger Provisions	O/C	2.7
- Cargo Accommodation System	?	?

*Penalty in commercial economics if militarily-desirable feature is incorporated in basic configuration.

**Penalty in military cost-effectiveness if commercially desirable feature is incorporated in basic configuration.

The features shown in Table 40 as possible hindrances involve much more subjective judgments. Consider first landing gear flotation. From a military viewpoint, the desirability of an LCG III flotation capability seems obvious. Yet, a military airplane with an LCG II capability may still be quite useful — despite being much less flexible than the LCG III alternative. That is, LCG II in the military case involves a difficult-to-quantify opportunity cost (O/C). Whether or not the poorer LCG II flotation is desirable commercially is also open to question. Such a capability, which is comparable to the flotation characteristics of a DC-8-63F, saves only 1.8 percent in direct operating cost while eliminating the possibility of operating into and out of about half the world's airports thought to be of commercial significance for the ACMA.

The passenger provisions feature represents the reverse situation. In this instance, not providing passenger provisions for combi operations could preclude some apparently profitable commercial operations (hence, an opportunity cost). Providing such provisions in the military aircraft, however, does not appear cost-effective. The reason, of course, is that cost-effectiveness analysis cannot reflect the benefits of moving troops in commercial-quality accommodations rather than in an austere, troop-pallet mode.

The last item shown in Table 40 is the cargo accommodation system. This feature has not been analyzed in detail in the current work because of time and resource limitations. However, we suspect that penalities are on the order of a few percent for both cases.

To summarize, Table 40 demonstrates that only a few transport aircraft design features tend to resist the concept of a joint civil/military airplane. Furthermore, those features that do resist commonality appear to represent only modest penalties in system cost — and these mainly to the military.

VIABILITY OF THE ACMA

The preceding summary suggests that, from a design viewpoint, the ACMA is a wholly tractable concept. Nonetheless, in our view, the ultimate success of a joint civil/military aircraft hinges on its commercial competitiveness.

To illustrate the potential of the ACMA in this regard, Figure 71 compares the direct operating costs of two of the configurations examined in this study with those of the most efficient contemporary commercial cargo aircraft, the 747-200F. In all cases, the same groundrules have been employed in the DOC calculation. Note that the LGA-144-400C (i.e., the commercial version of the configuration used as the baseline for the Group IV analysis) provides an estimated 34 percent improvement in DOC over the 3500 nm transatlantic stage length.

Somewhat more than half of this improvement (about 20 percent in absolute terms) is directly attributable to the advanced technology incorporated on this ACMA candidate. The remainder is about equally split between the effect of economies of scale and the design characteristics of the airplane. To illustrate the latter, notice the difference between the LGA-144-200C and the LGA-144-400C. We should also mention that the comparison presented in Figure 71 reflects essentially equal net payload densities in all cases. For the ACMA candidates, a net density of about 9.5 lb per cu ft can be achieved with main deck containers, assuming a container cross-section 8 ft wide by 9 ft high. For the 747-200F, a similar density is achievable at the 2250 nm stage length providing that both 8 ft by 8 ft main deck and lower deck containers (i.e., LD-1s) are used.

Of course, the differences shown in Figure 71 must be viewed with caution in the sense that the costs for the 747-200F are based on the present-day configuration; in the future, certain advanced technologies could be incorporated in derivatives of this contemporary airplane. For example, improved engines could be installed with, presumably, an improvement in DOC. Recall, however, that the technology that contributes the most to the superiority of the new airplanes is the assumed use of composites in primary as well as secondary structure. Blending composite technology into an existing design will, needless to say, have a smaller impact than in the case of a new design.

Fuel costs throughout the present study have been held constant at $0.50 per gallon (1978 dollars)—certainly a low estimate based on recent events. Figure 72 illustrates the differences in fuel efficiency between the

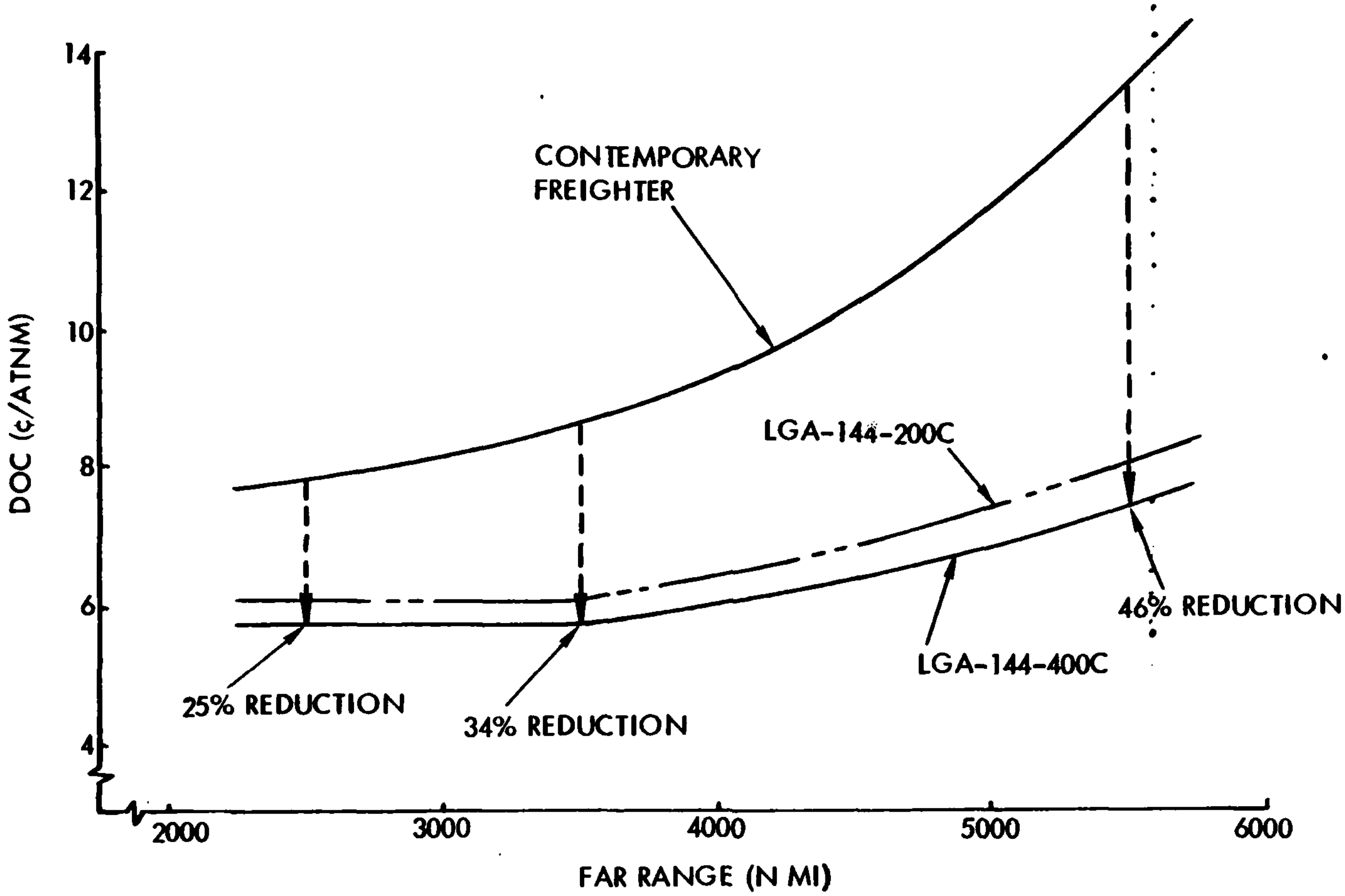


Figure 71. Comparison of Direct Operating Costs

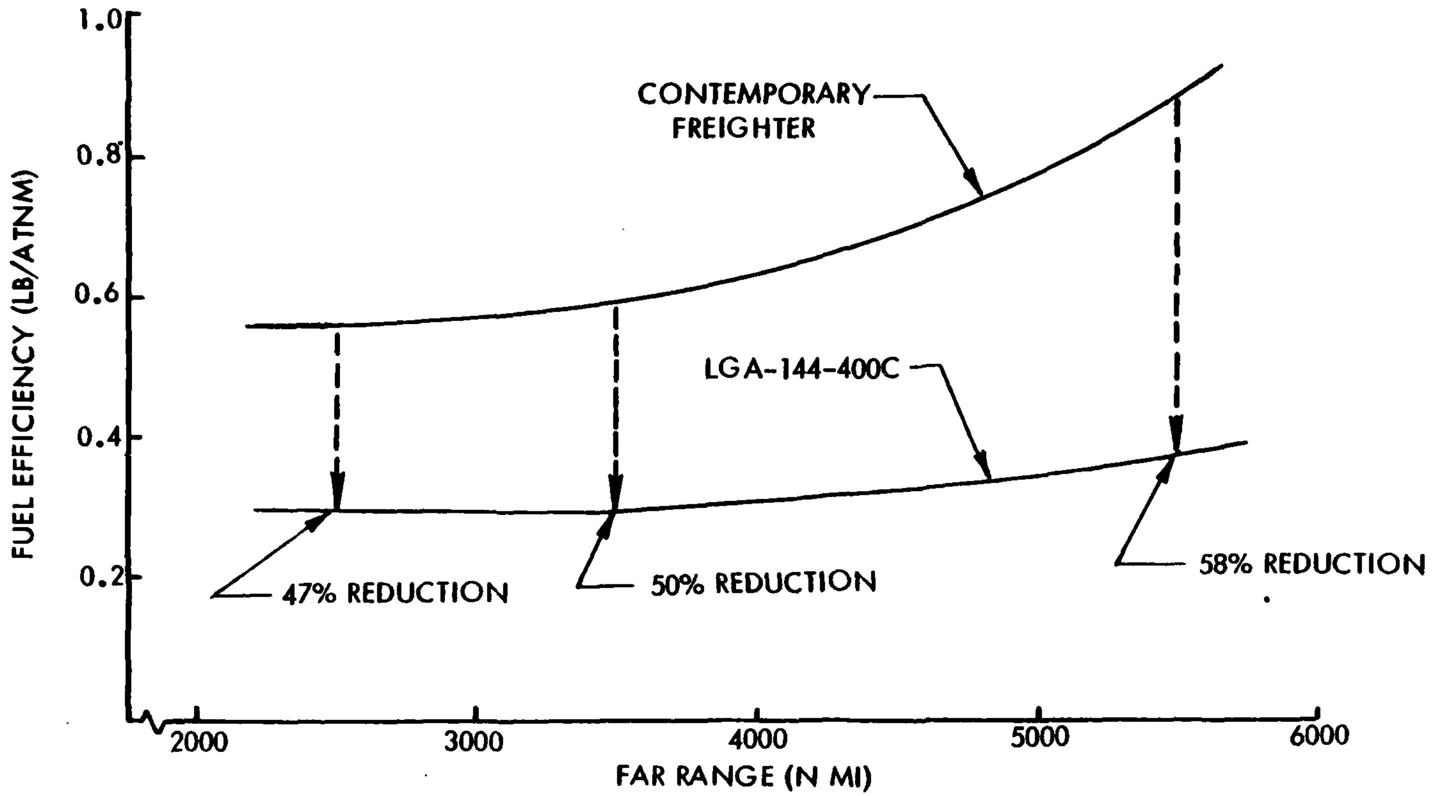


Figure 72. Comparison of Fuel Efficiency

contemporary airplane and the LGA-144-400C. Regardless of stage length, the ACMA candidate consumes about 50 percent less fuel per available ton-nm than the 747-700F. Obviously, as fuel prices increase beyond $1.00 per gallon, the DOC improvement can be expected to increase from 34 percent to almost 40 percent!

In closing, a final comment on the physical size of the aircraft examined in the study is worthwhile. Several times in the report, mention has been made of the benefits of economies of scale. To put the size of these aircraft in perspective, however, Figure 73 compares the characteristics of the C-5A and the LGA-144-400. Except for the greater wing span, there are no dramatic increases in any physical dimension for the LGA-144-400. (The greater wing span and concomitant increase in aspect ratio is an essential element of the improved fuel efficiency.) Thus, as demonstrated in Section VI, a new aircraft of the size discussed in this report should present relatively few problems in terms of compatiblity with existing ground systems.

These final comparisons suggest that not only is the concept of a joint civil/military transport aircraft viable, but that the configurations investigated in this effort are quite credible ACMA candidates.

	C-5A	LGA-144-400
DESIGN PAYLOAD (LBS)	220,000	390,000
DESIGN RANGE (NM)	3,250	4,000
GROSS WEIGHT (LBS)	769,000	1,038,600
WING SPAN (FT)	223	288
LENGTH (FT)	248	286

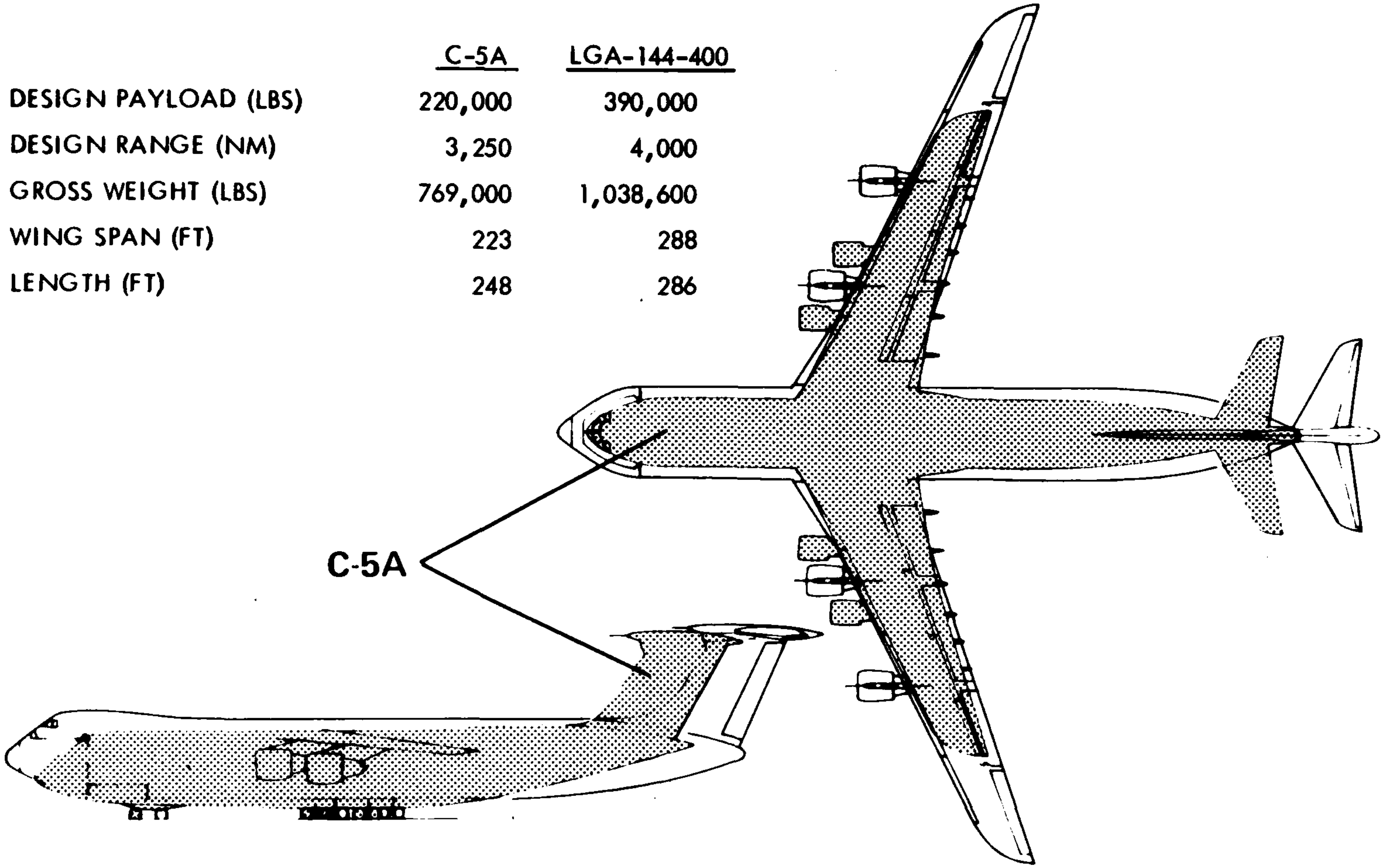


Figure 73. LGA-144-400 vs C-5A

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DESIGN OPTIONS AND ASSOCIATED MODEL NUMBERS				
GROUP	DESIGN FEATURES	DESIGN OPTIONS	MODEL NO.	DERIVED FROM
I	Design Payload	495,000 lb*	-100	-
		450,000 lb	-111	-100
		405,000 lb	-112	-100
		360,000 lb	-113	-100
		315,000 lb	-114	-100
II	Loading/Unloading Apertures	Front & rear with ADS kit provisions*	-200	-113
		Front only with no air drop capability	-211	-200
	Planform Shape of Cargo Compartment	Tapered forward and aft*	-200	-
		Full width Forward and aft	-221	-222
		Full width forward and tapered aft (with airdrop capability)	-222	-200
		Full width forward and tapered aft (with no airdrop capability)	-223	-211, -222
	Floor Height	8 ft kneeled and 13 ft unkneeled*	-200	-
		13 ft, no kneeling capability	-231	-200
III	Takeoff Distance/ Gear Flotation	8,000 ft/LCG III	-313	-323
		9,500 ft/LCG III*	-323	-200
		10,500 ft/LCG III	-333	-323
		9,500 ft/LCG II	-322	-323
		10,500 ft/LCG II	-332	-333
	Noise Characteristics/ Engine-Out Climb Gradient	No special acoustic treatment/2.5 percent*	-313, -323, -333	-
		Conform to FAR 36/3.0 percent	-343, -353, -363	-313, -323, -333
IV	Cargo Envelope (Maximum Height)	Constant 13.5 ft*	-400	-223
		Constant 11 ft	-411	-400
	Passenger Provisions	None (except bench seats in cheek)*	-400	-
		Integral high density passenger accommodations	-421	-400
		Integral medium density passenger accommodations	-422	-400
		Modular high density passenger accommodations	-423	-400
		Integral and modular medium density passenger accommodations	-424	-422
	Maximum Structural Payload	Corresponds to design range* (i.e., the design payload)	-400	-
		Corresponds to 3,500 n mi flight with takeoff at maximum gross weight	-431	-400
		Corresponds to 2,500 n mi flight with takeoff at maximum gross weight	-432	-400
	Service-Life Specification	30,000 hrs, military mission profiles*	-400	-
		60,000 hrs, commercial operational profiles	-441	-400
	Pressurization	8,000 ft (at 40,000 ft flight altitude)*	-400	-
		18,000 ft with baseline fuselage cross section	-451	-400
		18,000 ft with -411 fuselage cross section	-452	-411

* Incorporated in baseline aircraft (Model LGA-144-100)